Division of Research
Graduate School of Business Administration
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September 1984

VARIATIONS IN FLEXIBLE MANUFACTURING SYSTEMS ACCORDING TO THE RELEVANT TYPES OF AUTOMATED MATERIALS HANDLING

Working Paper No. 392

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ABSTRACT

In a previous paper, Browne et al. [1984] identified, defined, and described eight types of flexibilities that a flexible manufacturing system (FMS) can potentially have. These were used to classify FMSs into four types according to how flexible each type is. It was noted that an FMS's flexibility type is defined largely by its operating characteristics as well as by the versatility of its machine tools and the kind of material handling system that automatically moves parts from machine to machine.

This paper further develops and articulates the previous concepts of flexibilities with special emphasis on automated material handling systems. In particular, various types of automated handling systems that are relevant to parts handling in flexible manufacturing are discussed and categorized with respect to their relative flexibilities. Then, the four FMS types, in conjunction with the six types of material handling systems, are evaluated with respect to the relative amount of potential flexibility of each of the eight types. Finally, many existing FMSs are classified on the basis of the proposed classification scheme.

1. INTRODUCTION

A flexible manufacturing system (FMS) is a set of computer numerically controlled (CNC) machine tools integrated via automated material handling. Each machine tool has a limited-capacity tool magazine to hold all cutting tools for all operations that can be performed on that machine. Also, each machine has an automatic tool changer to allow the machining of several consecutive operations on a part without incurring set-up delays. The idea is to attain the efficiency of an automated transfer line, but in the area of small batch production.

A wide variety of manufacturing systems are being termed "flexible." These systems are flexible in different ways and to different extents. Some have the potential to be flexible but are operated inflexibly. Although the automated hardware is in place, it is sometimes difficult for an FMS manager to understand the usefulness of the flexibilities. Following visits to various FMSs, it was reported that "There was a general misunderstanding by senior managers of the amount and meaning of the flexibility they had purchased. There is a parallel to the misunderstandings which occurred in the early days of computers." Mortimer [1982, p. 98].

The plan of the paper is as follows. In §2, we review both the eight types of flexibilities as well as the four basic FMS types of Browne et al. [1984]. The kinds of automated material handling systems (MHSs) that have been or can be used in flexible manufacturing are described in §3 in terms of their flexibility potential. The feasible and typical combinations of FMS Types and MHS Types are evaluated with respect to the relative amounts of each of the eight flexibilities to result in an overall ranking of "flexibility potential" in §4. Also, many existing FMSs are categorized according to our proposed overall classification scheme of FMS Type/MHS Type. Finally, some observations are provided in §5.

2. FLEXIBILITIES AND FMSs

In this section, the flexibilities and FMS types defined in Browne et al. [1984] are reviewed. The relationships among the flexibility types are outlined in Figure 1. In brief, the flexibilities include the following:

1. Machine Flexibility measures the ease of making the changes required to produce a given set of part types.

2. Product Flexibility represents the ability to changeover to produce a new set of products economically and quickly.

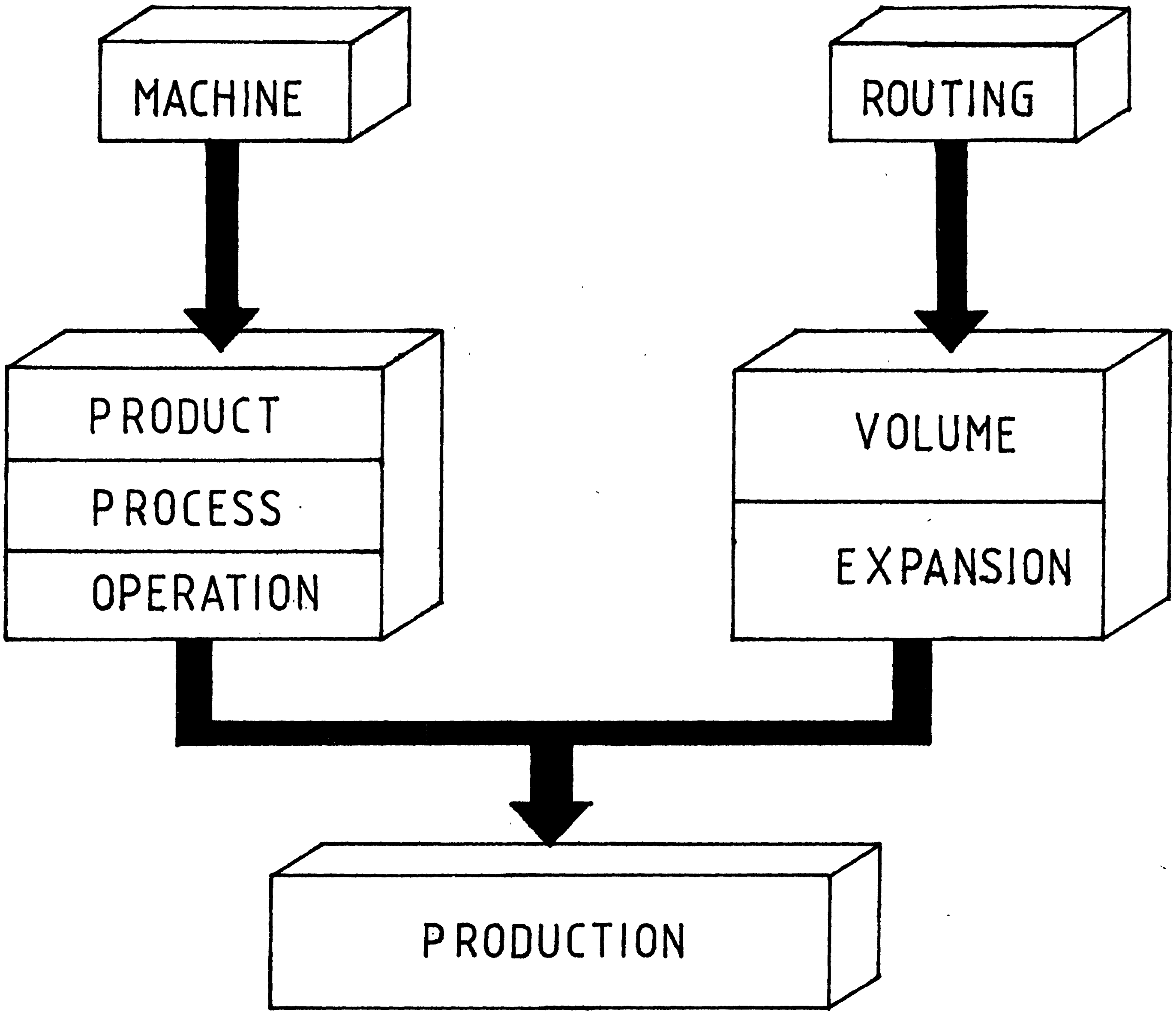

Figure 1

Relationship Among Flexibility Types.

3. Process Flexibility measures the ability to produce a given set of part types in several ways.

4. Operation Flexibility measures the ability to interchange the ordering of certain operations for each part type.

5. Routing Flexibility measures the ability to handle breakdowns while continuing to produce the desired set of part types.

6. Volume Flexibility measures the ability to operate an FMS profitably at different production volumes.

7. Expansion Flexibility represents the capability of expanding an FMS as needed, easily and modularly.

8. Production Flexibility represents the universe of part types that the FMS can produce.

All FMSs should have the potential to utilize these flexibilities to some extent. The basic types, required for all others, are machine and routing flexibility, the latter being the focus of this paper. The versatility of both the machine tools and the material handling system, comprising most of the FMS hardware, dictate the amounts of both the remaining flexibilities (see Figure 1) as well as the overall system flexibility. The software decisions concerning how the system will be run also heavily impact an FMS's overall flexibility.

The four basic FMS types of Brown et al. [1984] are now reviewed. A slash (/) ends each FMS type. These are later further subdivided in §4 with respect to the type of MHS, which will follow the slash.

1. Type I FMS: Flexible Manufacturing Cell (FMC) - An FMC consists of a single CNC machine tool with automatic tool changing and automated loading and unloading of parts from an associated buffer. Since it contains only a single machine, one might question whether an FMC should really be called a type of FMS. At the least, an FMC can be viewed as a component of an FMS.

2. Type II FMS: Flexible Machining System (FMS/) - An FMS/ is what is usually thought of as an FMS. It consists of FMCs or CNCs of possibly different types. Being the most general type of FMS, there are also several kinds of automated MHSs that can be used with this system to provide subcategories of this Type II, as we shall see in §4. Each FMC component may have its own buffer or the system may operate from a centralized buffer.

3. Type III FMS: Flexible Transfer Line (FTL/) - An FTL/ requires that each part have a fixed route through the system.

4. Type IV FMS: Flexible Transfer Multi-Line (FTML/) - An FTML/ consists of several FTL/s that are interconnected.

The latter three FMS Types will be further subdivided with respect to overall flexibility potential according to the type of MHS. The appropriateness of a particular MHS in part depends on whether the particular system machines prismatic or rotational parts.

Prismatic systems machine the large rectangular-type parts associated with horizontal or vertical boring mills, or horizontal-spindle machining centers, for example. An FMC for prismatic parts is provided in Figure 2. Because of the weight of the parts (they can be over 8000 pounds), automated pallet

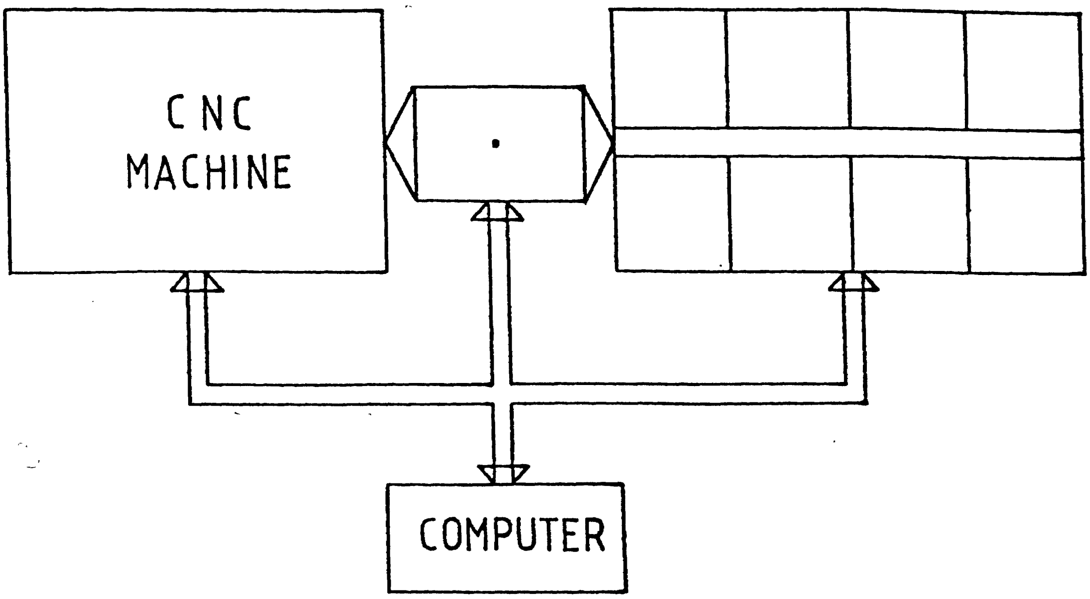

Figure 2

An FMC Example for Prismatic Parts.

changers are used to transfer pre-set, palletized parts from the CNC machine tool to either the buffer (in the case of an FMC) or to the MHS (in the case of an FMS). These palletized parts often require one or more refixturings, to be able to machine various facets of the workpiece.

Rotational systems machine much smaller cylindrical parts that require turning and grinding machine tools and lathes. Often the transfer from the CNC machine to either the buffer or the MHS is accomplished using a robot arm. An example of an FMC for rotational parts is shown in Figure 3. These two basic types of FMCs can be components of two different FMS types.

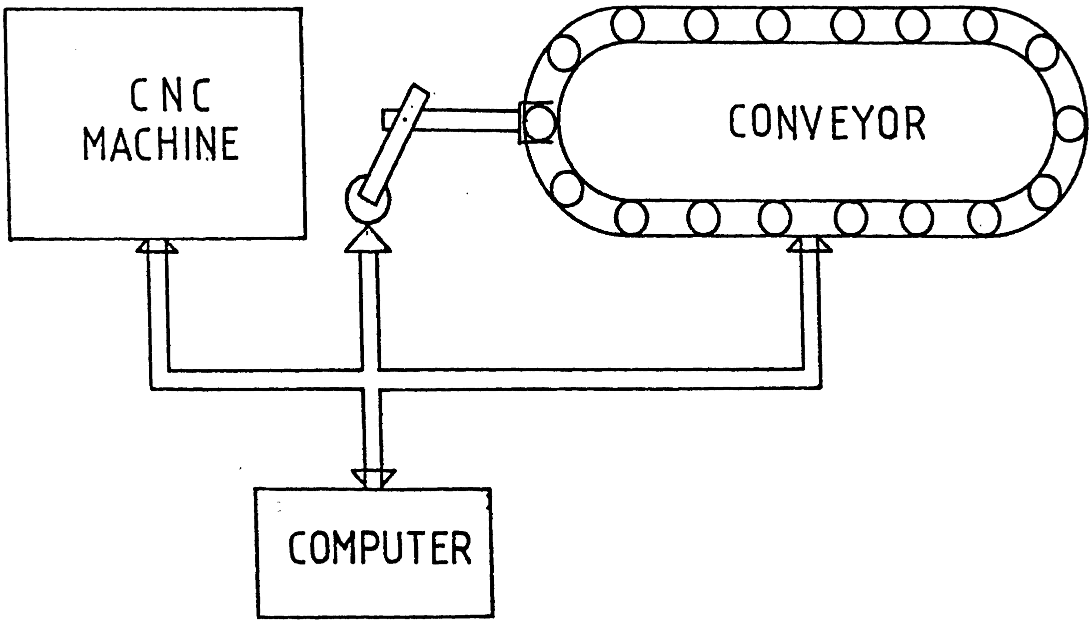

Figure 3

An FMC Example for Rotational Parts.

The various types of MHSs that can link the FMCs or CNCs are next outlined.

3. MATERIAL HANDLING SYSTEMS

In order of increasing potential flexibility, the various types of MHSs that can service an FMS and shall be described subsequently are: belt conveyors; powered roller conveyors; monotractors or monorails; power-and-free conveyors, both overhead and inverted; towline carts; and automated guided vehicle systems.

A belt conveyor (BC) is often used to transport parts down an assembly line, sometimes having work stations on both sides. When the appropriate "tote box" reaches the correct station, a robot arm can be used to pull it off.

A powered (chain or chain-driven) roller conveyor (RC) is similar in purpose to a belt conveyor in that movement is one way. The mechanical aspects are different.

Power-and-free conveyors (PC), both overhead and inverted, have trolleys located in a "free" rail, which are "powered" by a chain which is always moving. The chain is in a "power" track or rail on which is mounted the "free" trolley. The free trolley can engage and disengage at the appropriate machine tools.

A monorail or monotractor (M), although similar to the power-and-free conveyor, usually handles higher volumes and lower unit weights of material. A track contains the monorail, motor, and gearbox. A power rail provides electricity to each motor. Track switches allow movement into and out of each work station.

A towline (T) consists of carts that are usually powered by an in-floor chain. A fixed route is often followed. Machine tools can be skipped along the way. A towline can be a two-way system. Very few carts can be used then, because of possible traffic conflicts.

An automated guided vehicle system (AGVS) is the most flexible MHS type. An AGVS is self-powered via electromagnetic impulses transmitted from a guide wire imbedded under the plant floor. The vehicles can visit any machine tool in the FMS. The direct computer control allows rerouting when currently in movement, if need be. Of course, controlling the part-vehicle assignment is more complex than before. The AGVs are sometimes referred to as carts or shuttle cars or as robot carriers, for example.

A robot can be a flexible component in transferring small parts, usually turned components. (See Figure 6.) It is also possible to mount a robot on a track that conveys the robot up and down a line, to extend its effective work envelope. In this situation, the robot is conveyed via the MHS.

The first five of the six MHS types described above are all relatively fixed-route oriented, mostly different types of conveyors. Processing sequences are identical, similar to a flow-shop, except operations can be skipped. What ultimately determines the flexibility of the FMS is how it is operated. Some fixed-route, conveyor-type FMSs manufacture parts in large batches. Transportation times are short, but it is difficult to reconfigure the line for new part types.

The design decision concerning the choice of MHS type is important. The choice should match well with the desired mechanical requirements, which may include a specified speed, acceleration and deceleration, as well as load and size carrying capacity. It should provide the required design flexibility, perhaps including a lift and lower capability. Of course the MHS should be capable of computer control. Conflicts between carts need to be settled. Procedures to ensure that system deadlock does not occur need to be specified. For more complex MHS arrangements, methods to allocate parts to carts need to be specified.

4. COMBINATIONS OF FMS TYPES WITH MHSs

In this section, the flexibility ranges allowed within the FMS Types provided in §2 are indicated, first via examples of systems having a variety of components regarding types of both buffer and materials handling. Sometimes, an automated storage and retrieval system (ASRS) is referred to as "the MHS." However, an ASRS actually performs the function of a large buffer.

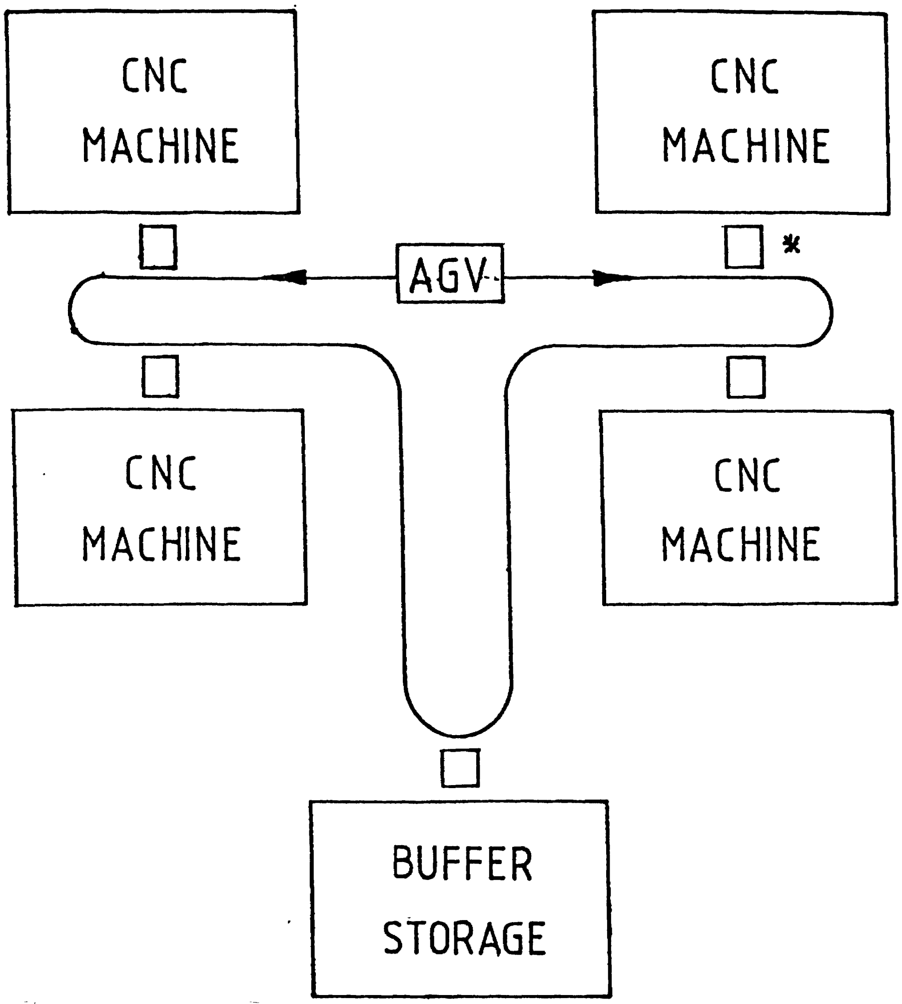

Figure 4

An FMS/AGVS with a Centralized Buffer.

A range of Type II FMS/ can be described according to whether the components of the system are CNC machine tools or FMCs. Figure 4 shows one possible configuration of a system of CNC machines. The buffer storage is central.

Figure 5 provides a configuration of a system of FMCs. In this case, the buffer is local. The transfer device between the AGV and the CNC or FMC may be either an automated pallet changer (APC) or a robot.

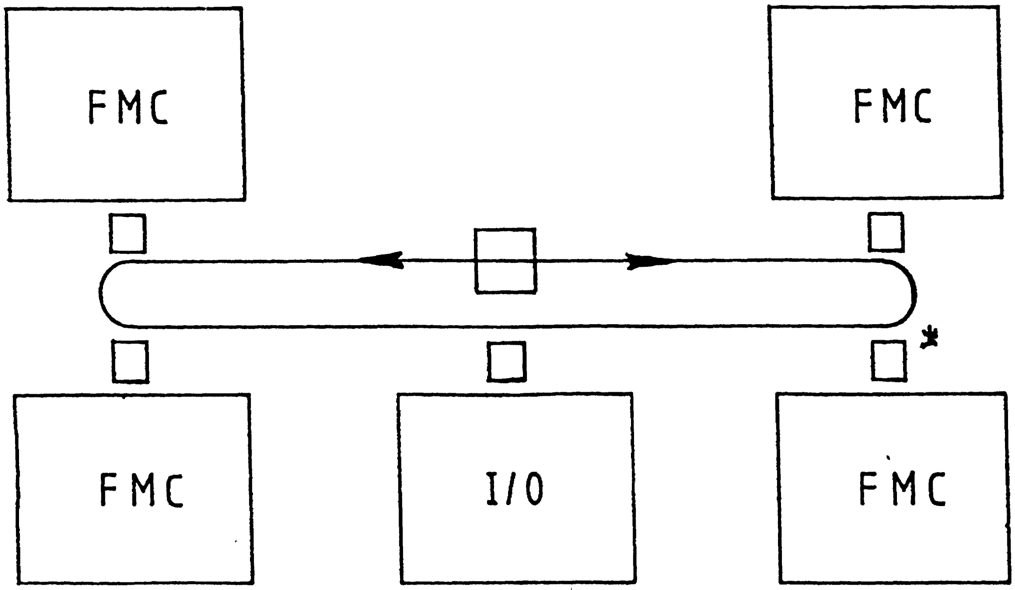

Figure 5

An FMS/Conveyor with Local Buffers at Each Machine Tool.

Figure 6 shows a robot-centered FMS. Two conveyors bring and take away parts. A robot tending three CNC machine tools transfer parts to and from the conveyor.

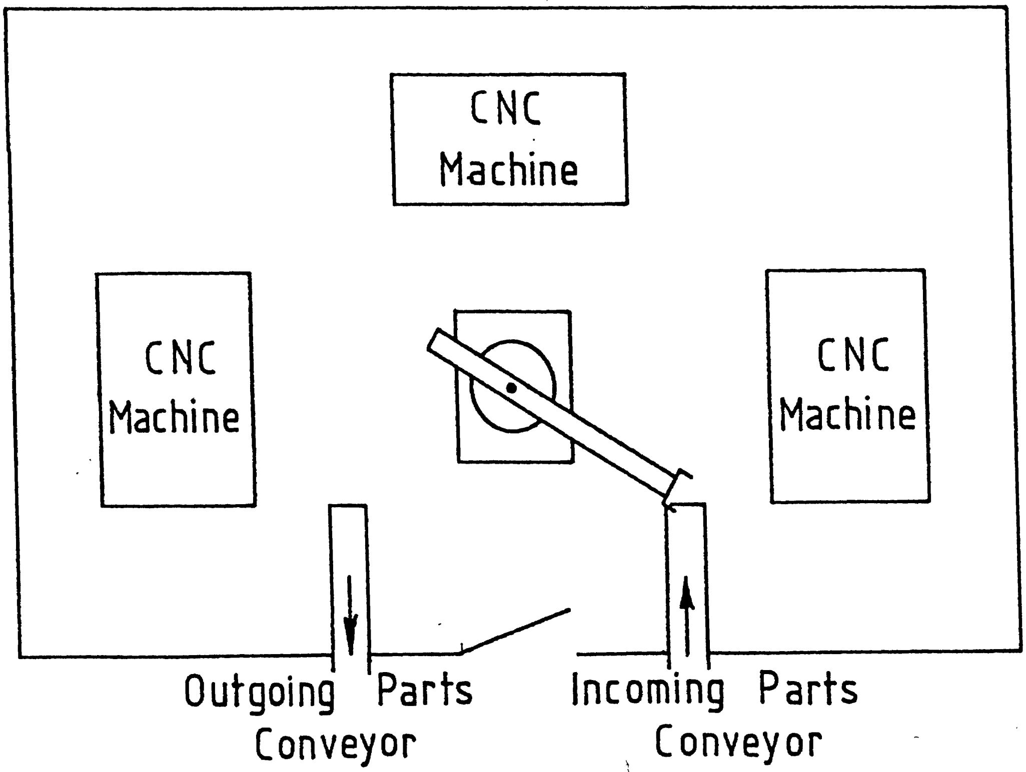

Figure 6

An/FMS/Conveyor/Robot-Centered.

Figure 7 provides an FTL having a conveyor with each robot loading and unloading a single machine tool. The route is unidirectional. However, a part may bypass a machine. Usually, batch sizes are large.

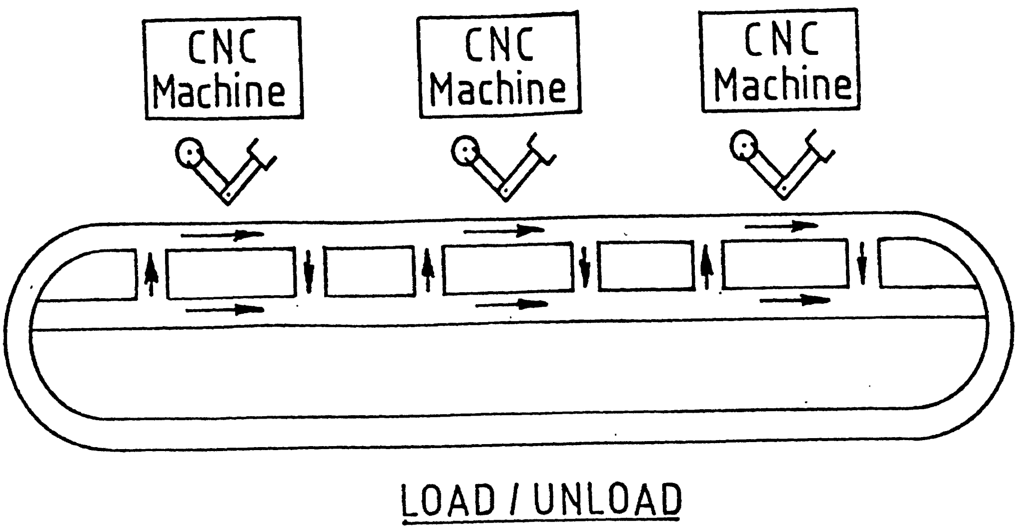

Figure 7

An FTL/Conveyor/Robots for Rotational Parts.

We will now summarize the observations to date. Table I ranks the four FMS Types with three MHS types according to 3 possible levels (high, medium, low) of each of the eight types of flexibilities. The last, production flexibility provides an overall flexibility index.

TABLE I

Evaluation of Various FMS/MHS Configurations
According to Levels of Flexibility

FLEXIBILITIES

	Machine	Routing	Product	Process	Operation	Volume	Expansion	Production
FMC	H	N/A	M	N/A	N/A	L	H	M
FMS/Conveyor	H	M	M	M	L	L	L	L to M
FMS/AGV	H	H	H	H	H	H	H	H
RMS/R	M	M	M	M	M	M	M	M
FTL	M	L	L	L	L	L	M	L
FTML	H	M	M	M	L	M	M	M

<u>Key</u>: N/A :Not Applicable
H :High
M :Medium
L :Low

Finally, we categorize many existing FMS installations throughout the world with their corresponding MHS types in Table II.

TABLE II

Existing FMS/MHS and Vendors

FMS	MAJOR VENDOR	TYPE
Hughes Aircraft Co. (CA, USA)	Kearney & Trecker (USA)	FMS/T
Kearney & Trecker (KY, USA)	Kearney & Trecker (USA)	FMS/C
Ford Motor Company (UK)	Ingersoll (USA)	FTL/C
General Motors Corp. (MI, USA)	Bendix Machine Tool Corp. (USA)	FTL/C
General Motors Corp. (MI, USA)	Comau Industriale SpA (Italy)	FMS/RC
Fiat Iveco (Italy)	Comau Industriale SpA (Italy)	FMS/RC
Volkswagen (W. Germany)	Burkhardt & Weber GmbH & Co. (WG)	FMS/
Caterpillar Tractor Co. (IL, USA)	Sundstrand Corp. (USA)	FMS/T
John Deere (IA, USA)	Kearney & Trecker (USA)	FMS/T
Yamazaki (KY, USA)	Yamazaki (Japan)	FMS/AGV
Ingersoll Rand (VA, USA)	Kearney & Trecker (USA)	FMS/C
Vought (TX, USA)	Cincinnati Milacron (USA)	FMS/AGV
Brother Industries (Japan)	Brother (Japan)	FTL
Fanuc (Japan)	Fanuc (Japan)	FMS/AGV
Murata (Japan)	Murata (Japan)	FMS/AGV
Okuma (Japan)	Okuma (Japan)	FMS/AGV
Yamazaki (Japan)	Yamazaki (Japan)	FMS/AGV
SCAMP (UK)	600 Group (UK)	FTL/C
Toshiba (Japan)	Toshiba (Japan)	FMC
Diag-Werner (W. Germany)	Diag-Werner (W. Germany)	FMS/Gantry
Gildemeister (W. Germany)	Max Muller (W. Germany)	FMC
Citroën (France)	Automatique Industrielle (France)	FMS/AGV
Borg Warner (USA)	Comau Industriale SpA (Italy)	FMS/RC
Caterpiller Gosselies (Belgium)	Scharmann GmbH (W. Germany)	FMS/AGV
Trumpf GmbH & Co. (W. Germany)	Friedrich Deckel Aktiengesellschaft (W. Germany)	FMS/pallet C
Messerschmitt-Bölkow-Blomh GmbH (W. Germany)	MBB (W. Germany)	FMS/AGV
Celákovice and Olomouc (Czechoslovakia)	VÚOSO (Czechoslovakia)	FMS/shuttle and rotary tables
Anderson Strathclyde (UK)	Giddings & Lewis Fraser (UK)	FMS/AGV
Renault Vehicules Industriels (France)	Renault Machines Outils (France)	FMS/AGV
Harris Corp. (TX, USA)	Cincinnati Milacron (USA)	FMS/T

5. CONCLUSIONS

We have attempted to indicate the ranges of potential flexibility in various types of FMSs as a function of the type of automated system chosen to transport the workpieces to be machined. The MHS highly impacts both the potential productivity as well as the flexibility of an FMS. The magnitude of the transportation times relative to the processing times affect the production.

We note that the MHS types that have been surveyed here refer to the movement of materials only. For most flexible systems to date, the cutting tools required for all operations are manually loaded into the tool magazines before production is begun. However, some systems have automated this procedure somewhat and have combined the movement of cutting tools with the movement of the palletized workpieces.

Some possibilities regarding the automation of cutting tool replacement include:

1. the delivery of the required cutting tools for the next operation with the part on an AGV;
2. the delivery and interchange of the complete tool magazines using an AGV;
3. an overhead delivery of a few tools at a time using, say, a conveyor to transport and a robot to interchange.

These possible embellishments of the future are beyond the scope of this paper. There are both advantages and disadvantages to automating tool delivery. In addition to providing additional flexibilities, automated cutting tool delivery also provides additional expense and problems by complicating the situation further. With automated tool delivery, there are new scheduling problems and additional delays introduced into the system.

We have examined and ranked FMSs and MHSs according to potential flexibility. We note that most FMSs do not use the available flexibility, but instead, choose to operate somewhat inflexibly, in part because it is easier to manage.

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