A comprehensive classification scheme for FMSs scheduling problems

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The current work presents a comprehensive classification and description scheme in the aim of highlighting and identification of the different level factors, which affect modeling and solution techniques of scheduling problems in Flexible Manufacturing Systems (FMSs). Five-field notation scheme is proposed in the current article. It takes into account the problem description, system configuration and capacity constraints, job description, production environment, and scheduling criteria. It compromises between the work done previously and helps to compare between different FMSs scheduling problems and models. Examples are given to demonstrate the utilization of the proposed scheme to describe and classify FMSs scheduling problems

هذا البحث يقدم مقترح تصنيف شامل للأنواع المختلفة من مشاكل الجدولة في نظم التصنيع المرنة. هذا التصنيف المقترح مكون من خمس رموز رئيسية كل منها مكون من مجموعة من الرموز الفرعية تبعا لموقع الرمز وتفرعاته. أيضا فان هذا التصنيف ياخذ بعين الاعتبار العوامل الهامة في نظم التصنيع المرنة مثل وصف مشكلة الجدولة وتركيبة نظام التصنيع وحدود السعة المتاحة في النظام ووصف العملية وظروف التصنيع ومعيار الجدولة المستهدف . تم شرح تفصيلي للنظام المقترح من خلال مثالين تطبيقين .

Keywords: Flexible manufacturing systems, Scheduling of FMS, Coding, Classification

1. Introduction

No doubt that the scheduling and control of Flexible Manufacturing Systems (FMSs) is a challengeable active research area in scheduling literature due to the high degree of flexibility, synchronization and control required by these systems, this resulting in a wide variety of models, approaches and solution techniques that deal with and solve this obstinate problem. In this aspect, the research had done focus on dividing the whole scheduling problems into two or more sub-problems. This division is in the aim of eliminating the computational and time limitation difficulties to find the optimal or even though a near optimal solution. This objective has been achieved through considering one or more of the capacity constraints of the whole scheduling problem. Some of these partial problems are part type selection, machine grouping, production ratio, resource allocation, part routing, Automated Guided Vehicles (AGVs) routing problem, loading problem, sequencing problem, tool loading problem, FMS scheduling and control problem, real-time scheduling problem and integrated problems. Finding independent solutions for some or all of scheduling sub-problems may lead to sub-optimal solutions for the overall scheduling problem due to the conflicting nature of these sub-problems in their objectives. These conflicting scheduling sub-problems led many researchers to combine two or more of these sub-problems and try to find an optimal solution for the overall combined problem. Some of the popular work done in integrated approaches are the machine loading and tool allocation problem by Sarin and Chen [1], part selection, load sharing and machine loading problem by Liang and Dutta [2], tool and machine allocation problem by Kato et al. [3], tool and machine allocation and routing problem Gupta et al. [4] and recently part loading, tool loading and part sequencing problem by Roh and Kim [5]. Due to this rich amount of problem types and scheduling approaches, there is a need to a comprehensive approach for description and classification of these collections of different

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problems characteristics and categories in a clearly and well-defined manner. If such a scheme exists the classification scheme should reflect, clarify, and demonstrate the different factors that affect the degree of both the simplicity or complexity of the FMSs scheduling problem. The presented paper first provides the previous work done in this field and then discusses the terminology and clarifies a number of terms used relevant to the FMSs scheduling problem. Also the different factors affecting the scheduling problem are described. Finally, a comprehensive scheme using five descriptors is developed and explained using examples to exhibit the application of the proposed scheme in describing the FMS scheduling problem under consideration

2. Literature review

One of the earliest and most popular methods that used to describe and classify a certain scheduling problem is the four-field notation scheme ($A/B/C/D$) by Conway et al. [6] where A is the number of jobs, B is the number of machines, C is the flow pattern of the machine shop and D is the performance measure by which the schedule is evaluated. While this descriptive technique is suitable for basic problems, when non-basic problems (involving pre-emption, dependent jobs, etc) require classification then the three-field notation ($\alpha/\beta/\gamma$) of Graham et al. [7] is more appropriate where α is the flow pattern and the number of machines, β is the constraints on the jobs and γ is the scheduling criteria. In addition Elsayed et al. [8] have introduced the five-field notation ($A/B/C/D/E$) scheme for describing and classifying a specific scheduling problem. The factors they consider are; A is the number of jobs to be scheduled, B is the number of machines in the machine shop, C is the type of manufacturing facility, D is the manner in which jobs arrive at the facility (static or dynamic), and E is the criterion by which scheduling alternatives will be evaluated (objective function). Recently, MacCarthy and Liu [9] indicate that the four-field technique developed by Conway et al. [6] has been widely used and is familiar to most scheduling researchers. Consequently they propose a combination of the scheme proposed by Conway [6] and the other proposed by Graham et al. [7] where the C field is modified to take into account non-basic models. Liu and MacCarthy [10] also propose a classification scheme of FMS scheduling problems. The FMS classification scheme elements are FMS type, capacity constraints, job description, production environment and the scheduling criteria. They had concluded that the proposed scheme did not attempt to be fully comprehensive but addressed the major scheduling problems in a wide range of real systems. As it is easily noticed from the presented literature review of the under consideration scope; no specific scheme can be easily applicable for the description of the wide varieties of FMS scheduling problems. The presented paper first discusses terminology and clarifies a number of terms relevant to FMS scheduling problem and also relevant to the integration use of the proposed scheme. The different factors that can affect the scheduling complexity in flexible manufacturing systems are then analyzed. This discussion provides the basis to the developed five-descriptors classification scheme. Finally, some examples are explained to verify and validate the implementation of the proposed scheme and hence conclusions are highlighted.

3. Clarification of terms and concepts

It is necessary to describe and clarify in a comprehensive manner the terminology used in FMSs scheduling problem in order to ensure that the same problem will be defined in the same perspective notation. The following definitions and clarifications will be used in this paper.

3.1. Parts, items, lot, job, operation, and batch

Parts are the objects in the FMS that undergo processing by the operations. Many parts may be subassembly parts that will not move forward to a station for an assembly operation unless another member of the assembly is already there. The terms part and item may be used to give the same meaning and may often be used interchangeably.

Lots are groups of parts that move as a unit through a process. The size of the lot may vary over time. It is initially determined when the lot arrives at the receiving area and it may be changed due to scrap production or disassembly of the lot as it flows through the processing stations.

A job may be defined here as finite quantity of a part type that have a routing of one or more operation(s) on one or more machine(s) in the FMS and needs to finite quantity of resources to complete the processing of all parts. A job order of one part type with quantity equal to one may be a part and a job but if the quantity of the same part type is increased to two or more we cannot name it by a part, it is a two-part job order.

An operation is defined as the processing over a continuous time period of a part (piece-part) on a machine under the availability of the required resources. It is performed by the overall integration between all processing requirements that is required to produce a new attribute for the processed part. For example, it may be processing, transportation, or washing operation. The operation may be simple or composite according to the number of parts that constitute the operation output; assembly operation is an example of the composite operation.

A batch is a collection of job orders that nearly use all machines, require a limited number of tools on each machine and have similar due dates for job orders in the batch.

3.2. Operation, part and job completion times

The commonly used regular performance measures are usually functions of the completion times. Here the definition of the job completion times can be defined as the time interval from the release time of the first part of the job until all parts that compromise the job leaves the system. The completion time of a part of a certain job can be defined as the time interval from the part release time to the time that part finishes all required operations and leave the system. The operation completion time of a part on a machine is the time when the part finishes its processing on that machine. According to the above definitions the completion time of the last operation of a part is defined as the completion time of the part not the completion time of the job.

3.3. Demand, job order and production order

The demand, job order and production order often be used interchangeably as they have the same meaning which the enterprise must deliver to the customer in the correct quantity at the correct time with the specified quality levels. Demand is defined as a certain piece-part types with specified quantities and qualities required by a customer at a certain specified delivery time. Job order is a subset of demand of only one-piece part type and the production order is a number of job orders that must be completed in a certain time horizon. It may be necessary to split each production order into batches in the aim of achieving certain specified manufacturing objectives. A one batch may be consists of one or more job order.

3.4. Part type selection problem

The part type selection problem determines the subset of part types (batch of job orders) for production during a predetermined period of time for which the short-term production-planning problem is defined—usually 2 weeks [11]. The most of all FMSs scheduling problems are subordinate for the part type selection problem. Objectives of part type selection problems are time minimization of total production, time minimization between two successive batches, time minimization within each batch, time minimization of parts total throughput, minimization of number of batches required to process all parts and maximization of average machine utilization over all batches.

3.5. Machine grouping problem

Machine grouping problem partitions machines of similar types into identically tooled machine groups, which consists of number of machines that capable of performing the same operations in order to assigning each operation to only one machine or each machine in a group. Grouping machines introduces Unidirectional Alternate Routing (UAR).

Without grouping, all routing are fixed (UFR) and have a predefined flow through the system as specified by a part type's routing sheet. Having machine groups or cells ensures that the system has a transfer-line-like efficiency and a job-shop-like flexibility. Objectives of machine grouping are; reduction of operating costs, minimization of total cell load variation among machines, cost minimization, cost minimization of duplicating machines, maximizing the sum of machine similarities within the cells, minimization of intercellular movements, and maximization of the association of part operations within machines.

3.6. Production ratio problem

Production ratio problem determines the part mix ratios in which the selected part types should be produced. For example, if the production order consists of three different jobs A, B and C, the solution of the production ratio problem is producing one part A, two parts B and one part C in order to balance the workload on the FMSs resources.

3.7. Resource allocation problem

Primary resources of FMSs include machines, tools, material-handling devices, fixtures, pallets and storage buffers. The resource allocation problem is defined as the allocation of these primary resources to the selected part types based on predetermined production order to provide FMS with the flexibility that allow the manufacturing system to respond quickly to dynamic changes. Stecke and Browne [12] and Kulatilaka [13] observed that most FMS scheduling researchers ignore the resource allocation problem and conclude this to ease analysis.

3.8. Part routing problem

Routing problem is the process of optimal path determination. In FMSs scheduling problems, part routing problem may be defined for parts or material handling devices such as AGVs. The part routing problem is defined as the route determination or sequence of machines for each part passing through the system.

3.9. AGVs routing problem

According to Tanchoco and Taghaboni [14], primary vehicle management functions for an AGV system are dispatching, routing, and scheduling.

- *Dispatching* is the process of selecting and assigning tasks to vehicles.
- *Routing* is the selection of certain specified paths for part types driven by vehicles to reach their destinations.
- *Scheduling* is the determination of arrival and departure times of vehicles at certain points along their prescribed routes to ensure collision-free journeys.

It is evident that AGVs routing is the determination of the optimal flow path and minimization of total travel of loaded and empty vehicles. It may be either static or dynamic routing. In static routing environment the AGV path between any two given nodes is always the same but it is varying over time in dynamic routing environments.

3.10. Loading problem

Loading problem includes the assignment of tools and part operations to specific machines. The assignment of pallets and fixtures to part types are also included. Machine loading refers to the process of allocating tools to machines before the start of production period with the assumption that the loaded tools will stay on the machine during the production period.

3.11. Sequencing problem

Sequencing problem is the order determination in which batches will enter the manufacturing system. Also, operation sequencing is the order determination in which operations will be performed on machines.

3.12. Tool loading problem

Tool loading problem is the scheduling of jobs with the accompanying tool changes. Within this problem, job scheduling and tooling problems are exist. Job scheduling refers to the ordering of jobs to minimize the required time to process jobs set. Tooling refers to the ordering of tool changes to accommodate the job schedule and minimize the processing time.

3.13. FMS scheduling and control problem

FMS scheduling and control problem concerns with order review and release, dispatching and the system ability to take corrective action when system components fail. From the definition, it is noted that the elements of the FMS scheduling problem are order review/release problem, dispatching problem, and FMS control problem.

3.13.1. Order review/release problem

The order review/release problem is the process of selecting a part to be loaded on a pallet and released to the system.

3.13.2. Dispatching problem

Liu and MacCarthy [10] define the dispatching as an element of FMS scheduling problem that concerned with decisions of determining the next operation for a resource when the resource becomes available and determining the next destination of a part when its current operation has been finished.

3.13.3. FMS control problem

FMS control problem deals with the control actions that must be taken when reality deviates from plan. How should parts be rerouted when a certain system component fails?

3.14. Real-time scheduling

FMS states change dynamically, so it is necessary to schedule flow of parts based on actual system states. The real-time scheduling means such scheduling actions responding to system state changes in real time.

3.15. Integrated approaches

Some researchers attempt to solve some of the scheduling sub-problems simultaneously seeking to solve the overall scheduling problem. It is clear that finding an independent optimum solution to one or more of these subproblems don't guarantee an optimum solution to the FMS scheduling problem. For example some researchers try to solve loading and routing concurrently as the work done by Sarin and Chen [1], and the work done by O'Grady and Menon [15] and Chen and Chung [16]. Others try to solve part selection and machine loading problem as the work done by Liang and Dutta [2].

3.16. Methods of applying FMSs

Parrish [17] has concluded that there are five methods of applying FMSs. These methods are sequential, random, dedicated, engineering and modular FMSs. Sequential FMSs manufactures one-piece part batch type, and then planning and preparation are carried out for the next piece part batch type to be manufactured. It operates like a small batch flexible transfer line. Random FMSs manufacture any random mix of piece part types at any one time. In contrast to the random FMSs the dedicated type continually manufactures, for extended periods, the same but limited mix of piece part batch types. Engineering FMSs manufacture the same mix of part types throughout its lifetime. Finally, Modular FMS is an FMS with a sophisticated host that enables an FMS user to expand FMS capabilities in a stepwise fashion into any one of the previous four types of FMSs.

3.17. Station, machine tool, location and work cell

Station is a location where an operation may occur. Stations typically may be machines, work cells, or other physical objects where work is performed. The term machine tool is often used to represent a machine that uses tools. Location is a space area in the shop floor ground that may contain one or more machine. One must note the difference between a station and a machine tool where every machine tool must be a station and the reverse is incorrect. Three types of stations are exist; normal, chamber and batch station. Normal stations can perform only one operation at a time where chamber stations like ovens or etching tanks can perform one operation at a time like normal stations, but they may contain several parts at one time. Batch stations collect certain number of parts before the operation beginning. The work cell is defined as a number of identical or semi-identical tooled normal stations that connected together by one material-handling device.

3.18. FMSs machine configurations

MacCarthy and Liu [9] have presented a four-classification scheme for FMS configurations based on their operational characteristics. These four configurations are Single Flexible Machine (SFM), Flexible Manufacturing Cell (FMC), Multi-Machine Flexible Manufacturing System (MMFMS) and Multi-Cell Flexible Manufacturing System (MCFMS). A Single Flexible Machine (SFM) is a computer controlled production unit that consists of a single CNC or NC machine with tool changing capacity, material handling device and part storage buffer. A flexible manufacturing cell consists of a group of single flexible manufacturing machines sharing one common material-handling device. A multi-machine flexible manufacturing machine consists of a number of SFMs connected by an automated material handling system that includes two or more material handling devices or is otherwise capable of visiting and serving two or more machines at a time. A multi-cell flexible manufacturing system consists of a number of FMCs, and possibly a number of SFMs if necessary, all connected by an automated material handling system.

3.19. Scheduling objectives

Balogun et al. [18] classify the scheduling objectives as two major classes primary and secondary objectives. The primary objectives include the objectives concerned with satisfying customer demands. The second class of objectives is classified as four subclasses, which are transport efficacy, machine efficiency, capacity utilization and other miscellaneous objectives. They proposed that only objectives directly relevant to customer's demands should be employed as the primary objectives in dynamic scheduling of a FMS, and that the objectives related to internal efficiency of the FMS can play at most a secondary role. We note that, as JIT concepts become more popular objective for FMSs manufacturers, the minimization of sum of the earliness scheduling-objective will be of a major interest from the researchers and the developing of robust schedules is a recently not yet well-defined objective where it is not clear how robustness is maximized.

4. Factors affecting FMSs scheduling problems

Different factors are affecting the FMSs scheduling problem. These factors describe the attributes of the manufacturing system, tightness of resource constraints, flexibility and complexity. The following are the most widely used factors:

- Number of machines.
- Maximum number of different jobs produced simultaneously in the scheduling model.
- Average number of piece-parts per job type.
- Tool magazines availability and capacity.
- Availability and type of material handling system.
- Types and availability of fixtures.
- Types and availability of pallets.
- Types and availability of tools.
- Size of storage buffers.
- Average number of operations per job.
- Average number of tools per operation.
- Average number of permissible machines per operation.
- Range of processing times.

5. Classification scheme of FMSs scheduling problems

The proposed five-notation $(A/B/C/D/E)$ classification scheme is described as shown bellow:

The problem description	FMS configuration and capacity constraints	Job description	Production environment	Scheduling criteria

‘*A*’ indicates the scheduling problem description part. It consists of three elements separated by a comma. The first element represents the scheduling problem type that may be one of the famous fourteen valid scheduling problem types. These problem types are:

PS: Part type selection problem
MG: Machine grouping problem
PR: Production ratio problem
RA: Resource allocation problem
PR: Part routing problem
AR: AGVs routing problem
LP: Loading problem
SP: Sequencing problem
TL: Tool loading problem
OR: Order review/release problem
DP: Dispatching problem
CP: FMS control problem
RT: Real-time scheduling problem
IA: Integrated approaches

The second element corresponding to process flexibility levels. The different levels of it are Unidirectional Fixed Routing (UFR), Unidirectional Alternate Routing, (UAR) and Multidirectional Alternate Routing (MAR).

The third element corresponding to the type of manufacturing planning and control system if it is based on static, dynamic, or hybrid release of jobs to the shop. We will denote for them consequently by S, D, and H. For example, in order to denote to a part selection problem and a unidirectional fixed routing process flexibility in a manufacturing planning and control system based on a static release of jobs to the FMS shop, we can say that this is a $|PS, UFR, S|$ problem.

‘*B*’ Indicates FMS configuration and the capacity constraints description of the scheduling problem. This perspective consists of seven elements that give information about machine configuration, machine's magazine and tool magazine capacity constraints, material-handling devices, fixtures, pallets, tools, and storage buffer capacity constraints.

The *first element* indicates the machine configuration scheme and number of machines that compromise FMS. The machine configuration is one of the four types SFM, FMC, MMFMS and MCFMS. Number of machines that compromise the FMS may be represented as a SFM for single flexible machine, FMC [*n*] for flexible manufacturing cell with *n* machines, MMFMS [*n*] for multi-machine flexible manufacturing system of *n* machines and MCFMS [total number of machines/number of cells/average number of machines per cell] for multi-cell flexible manufacturing system. For example, MCFMS12/3/3.3 is representative for multi-cell flexible manufacturing system of twelve machines that compose of two single flexible machines and three cells each with 3.3 machines on the average.

The *second element* represents the machine's magazine and tool magazine capacity constraints. This will be represented in the form of [average number of magazines per machine/tool magazine capacity]. For example, MMFMS6, 1/72 indicates a system consisting of six machines each of seventy-two tool slots on the average.

The *third element* represents the capacity constraints for material handling system (MHS) devices. It demonstrates the MHS type, total number available and capacity for each automated material handling device type on average. The following notations are available.

Automated guided vehicles	: AGVs[number/capacity per AGV]
Rail guided vehicles	: RGVs[number/capacity per RGV]
Conveyors	: CONs[number/capacity per CON]
Robots	: ROPs[number/capacity per ROP]
Gantry Robots	: GROP[number/capacity per GROP]
Stacker crane	: CRN[number/capacity per SCRN]
Tow Carts	: TCRT[number/capacity per TCRT]
Rail Carts	: RCRT[number/capacity per RCRT]

The *fourth, fifth* and *six elements* represent fixtures capacity constraints, pallets, and tools respectively. The following notation is valid for representing these constraints [total number of resource of all available types/number of different resource types used].

The *last element* is representative to storage buffer capacity constraints. The available capacity of storage buffers is denoted by total number of storage places that exist in the FMS. For example, AGVs4/1,100/1, 150/5, 100/5, 20 represent an FMS that have 4 AGVs each of one unit capacity, 100 fixtures of the same type, 150 pallets of 5 types, 100 tools of 5 tool types and a total of 20 buffer storage capacity exist in the FMS.

'*C*' Indicates the job description of the proposed notation. This section represents both the complexity and routing flexibility of the job. It consists of six elements. The first five elements of this part are:

- Maximum number of different jobs.
- Average number of piece-parts per job type
- Average number of operations per job.
- Average number of tools per operation.
- Average number of permissible machines per operation.

The sixth element depends on the operational characteristics of the job (s) that used in the scheduling model like preemption and dependency. This element will consist of two alphabetic letters as shown bellow.

N: Preemption not allowed
U: Preemption resume
R: Preemption repeat
D: Dependent job
I : Independent job

For example 12,10,2.2,5,3,NI represent a problem with 12 different job types each of which has on the average 10 piece-parts. Each job type has 2.2 average numbers of operations per job, 5 tools per operations are permissible on the average. 3 is representative of the average number of machines per operation. Finally NI represents that non-preemption and independent job-scheduling problem.

'*D*' Indicates the production environment of the proposed notation. In the current article the abbreviations proposed by Liu and MacCrathy [10,21] are used with some modifications. One part per type and more than one part per type are substituted by the average number of piece-parts per job type and demonstrate this factor in the job description part as demonstrated in the previous part of the proposed scheme. Why? The first element in this part represent if the management production policy is make to order or make to stock, the second will represent the operational policy if it is based on part moving policy, tool moving policy or hybrid policy. The third element will represent whether there is a ratio request or batch size request of both of them. The coding scheme with suggested modification for completeness is as shown bellow:

MS : Make to stock
MO : Make to order
PM : Part moving policy
TM : Tool moving policy
HM: Hybrid part and tool moving policy
RR : There are ratio requests
BR : There are batch size requests
HR : There are ratio and batch size requests

'*E*' Indicates scheduling criteria for system under consideration. The following abbreviations are valid [8,11] to be used in the classification scheme for integration purposes.

L_{max} :Minimization of maximum lateness
N_t :Minimization of number of tardy jobs
TT :Minimization of total tardiness
$\overline{T}$:Minimization of average tardiness
TWT :Minimization of total weighted tardiness
$\overline{C}$:Minimization of mean completion time
TCSO :Tardiness cost per supplied order
$\overline{F}$:Minimization of mean flow time
$\overline{W}$:Minimization of mean waiting time
C_{max} :Minimization of make-span
l_{min} :Minimization of order lead time
R_{max} :Maximization of throughput rate
RUB :Ratio between actual throughput and an upper bound
CLV :Minimization of total cell load variation
MSM :Maximization of machine similarity within cells
OPO :Maximization of part association operations of machines
WIP :Minimization of in-process inventories
UTIL :Maximization of FMS utilization
MDM :Minimization of duplicate machines
MUT :Maximization of average machine utilization
TMT :Minimization of total machining time and cost
TT :Average throughput time
SCT :Minimization of the sum of completion times
SWT :Minimization of the sum of weighted completion times
SOE :Minimization of the sum of earliness

Rubs :Maximization of the schedule robustness
TPT :Minimization of total production time
TBB :Minimization of time between production batches
FRD :Flexibility to meet rapidly changing resource demands
TotT :Minimization of total throughput time
MNB :Minimization of number of batches
DUM :Minimization of disparity in utilization of machines
TolC :Minimization of tool changes
UNP :Minimization of unproductive time
FRA :Flexibility to meet rapidly changing resource availability
MHM :Optimization of material handling movements
ICM :Minimization of cost or distance of inter-cellular moves
CDI :Minimizing total number of part transfers
AGP :Optimization of AGV flow path
EAG :Minimization of empty AGV journals

The proposed five-notation scheme tends to describe clearly and comprehensively the different characteristics of the FMSs scheduling problem. Also, it defines the most commonly known factors that affect the complexity of the problem. This scheme facilitates to evaluate and compare between different FMSs scheduling problems and classify them in a comprehensive and easy manner.

6. Illustrated examples

The following illustrated examples we tend to use the propose scheme to demonstrate its validity

6.1. Example 1

Jeong and Kim [19] improved and extended a previous research on simulation-based real-time scheduling. It can be stated clearly as follows using the classification scheme introduced in this paper.

The problem description:	Real-time scheduling and control	RT
	Unidirectional alternate routing	UAR
	Static job release	S
FMS configuration:		
	Type	MMFMS
	Number of machines	Six HMCs
Capacity constraints:	Tool magazines	N/A
	Material handling system	SCRN1/1
	Fixtures	N/A
	Pallets	150/1
	Tools	N/A
	Storage buffers (work-piece stoker)	1/150
Job description:	Maximum number of different jobs	15
	Average number of operations per job	4.5 ≅ 5
	Average number of piece-parts per job type	11.25 ≅12
	Average number of tools per job	N/A
	Average number of permissible machines per operation	2
	Non-preemption and independent job	NI
Production environment	Make to order environment	MO
	Part movement policy	MO
	There is no ratio or batch size requests	N/A
Scheduling criteria:	Mean flow time	$\overline{F}$
	Mean tardiness	$\overline{T}$

Using the proposed classification scheme this problem can be represented by the following notation;

$$\left|\text{RT,UAR,S}\right|\text{MMFMS6, SCRN1/1,150/1,,1/150}\left|\text{15,5,12,,2,NI}\right|\text{MO,PM,}\left|\overline{\text{F}},\overline{\text{T}}\right|.$$

6.2. Example 2

Arzi [20] described a real time scheduling as:

The problem description:	Real-time scheduling problem	RT
	Multidirectional alternate routing	MAR
	Dynamic job order release	D
FMS configuration:		
	Type	MCFMS
	Number of machines	9
	Number of cells	2
	Average number of machines per cell	4.5
Capacity constraints:	Tool magazines	N/A
	Material handling system	N/A2/1
	Fixtures	N/A
	Pallets	N/A
	Tools	N/A
	Storage buffers	2.5/270 ≅3/270
Job description:	Maximum number of different jobs	12
	Average number of operations per job	3.5
	Average number of piece-parts per job type	3
	Average number of tools per job	N/A
	Average number of permissible machines per operation	1.951≅2
	Non-preemption and independent job	NI
Production environment	Make to order environment	MO
	Part movement policy	PM
	There is no ratio or batch size requests	N/A
Scheduling criteria:	Ratio between actual throughput and an upper pound	RUB
	Tardiness cost per supplied order	TCSO

|RT, MAR, D|MCFMS9/2/4.5,, N/A2/1,,150/1,,3/270|12,3,3.5,,2, NI|MO, PM, |RUB, TCSO|.

7. Conclusions

A comprehensive classification of five-notation scheme for FMSs scheduling problems has been presented. The proposed scheme reflects and demonstrates the different factors belong to the complexity of the FMS scheduling problem. Five categories are considered in the proposed classification scheme. These categories include type of problem, scheduling model, configuration and description of problem capacity constraints, job description, production environment adapted by management, and performance criteria. The comprehensive approach proposed here attempts to distinguish between different FMSs scheduling problem types. It has the advantage of easy comparison between different works in the same category. By using the presented scheme in describing different types of scheduling problems, the tools and approaches that are used as solution techniques and procedures can easily be unified for different problem classes. This unified system will support the industrial manager in his decision-making. Also, the authors recommended that the presented scheme be considered as the first step in standardization of FMS scheduling problems or towards the construction of FMS-ISO. The FMS-ISO should define all the FMS characteristics that must be considered when researchers tackle any FMS scheduling problem.

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