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Manufacturing configuration selection under arduous working conditions: A multi-criteria decision approach

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***Abstract*— One of the issues encountered in Reconfigurable Manufacturing Systems (RMS) is related to the evaluation and selection of a new configuration among a set of available alternatives to meet unexpected and unpredictable changes/disturbances. Configurations are often evaluated using indicators that are mainly related to performances of technical components of a manufacturing system, assuming that the working environment is safe and healthy. Unfortunately, this assumption is often unrealistic, since it does not take into account some arduous working conditions (such as sustained physical or mental efforts, heavy noise, etc.), which may lead to high instances of sickness leave, inability to operate some equipment, damage to equipment or products, etc. Thus, the best configuration, selected based on product or equipment performance only, can turn out to perform poorly if, for example, required operators are absent or less productive than expected. In this paper, we suggest some human factors and ergonomics related indicators that allow taking into account arduousness of working conditions when reconfiguring a manufacturing system. An Analytic Hierarchy Process (AHP) is developed to assist decision makers in selecting configurations based on both technical and human performance. The results of our experiments show the importance of considering such human factors and ergonomics issues in reconfiguring manufacturing systems.**

Keywords*— Reconfigurable Manufacturing; work arduousness; multi-criteria decision making; AHP.

I. INTRODUCTION

Nowadays, manufacturing companies have to deal with increasingly severe market conditions and highly changing customer requirements. To ensure competitiveness, these companies must possess more efficient, flexible, agile and responsive production systems, which can be adapted to change rapidly and cost effectively [1], [2]. Reconfigurable manufacturing systems (RMSs) offer rapid adaptation capabilities of both their production capacity and functionality to overcome new situations [3]. One of the issues encountered in RMSs relates to the evaluation and selection of a new configuration among a set of available alternatives to meet new requirements [4]–[8]. Many product or equipment related performance indicators were commonly used to evaluate available configurations, such as throughput, work in process, product tardiness, etc. [7], [9]. Some other indicators were also considered that are more related to the ease of reconfiguration and the capacity of the system to evolve, such as modularity, reconfigurability, convertibility, etc. [10]. Unfortunately, all these indicators are related only to physical (hardware) and technical components of the manufacturing system. They do not take into account aspects related to human factors and ergonomics. Therefore, they may be limited and lead to a solution that is not safe, healthy or comfortable for operators. Neglecting human aspects when reorganizing systems is often far from reflecting both real operating conditions in workshops, occupational health and safety standards, ergonomics recommendations, and requirements of labor codes, supported and promoted by governments and labor authorities. It is well established that the arduousness of work, due to factors like steady physical or mental efforts, heavy noise, complex and repetitive activities, may lead to low morale and sickness, and therefore high instances of sickness leave and absenteeism [11], as well as high accident rates, and therefore damage to equipment and/or products [12]–[14]. The best configuration, evaluated and selected based on product or equipment performance only, can turn out to perform poorly if, for example, the required operators are absent or perform poorly due to resulting arduous working conditions [15], the needed machine is damaged, or the products do not meet quality requirements.

In this article, we present a multi-criteria configuration evaluation and selection approach that integrates both technical indicators to quantify performance, and human factors related indicators to quantify the arduousness of work. Contrarily to existing methods, which mainly and almost exclusively focus on technical indicators to evaluate performance, we consider both human and technical aspects, which is a more realistic and human centered view of manufacturing systems. The evaluation of configurations is based on a multi-criteria outranking methodology that is achieved with an Analytic Hierarchy Process (AHP) [16], which is widely used in this context [6], [7], [17]–[19]. Therefore, this paper is organized as follows. In section 2, we provide an overview of related works. In section 3, we present the work arduousness and the related indicators. In section 4, the decision-making process for configuration selection whilst considering human and technical indicators is presented. In section 5, a case study illustrates the benefits of the proposed approach. Section 6 concludes the article and suggests future research directions.

II. Related Works

Several multi-criteria decision making methods have been suggested in the literature to address the configuration evaluation and selection problem in RMSs. We cite the analytic hierarchy process (AHP) [17]–[21], the Fuzzy AHP [5], [6], [22], [23], ELECTRE [19], PROMETHEE [7] and optimization techniques [4], [8]. Speredelozzi and Hu [17] tackle the problem of configuration selection in the design stage of a manufacturing system. The indicators used to evaluate the alternative solutions are scalability, convertibility, reliability and maintainability. Rehman and Babu [19] and Rehman [7] address specific manufacturing systems, in which the available configurations are evaluated according to performance indicators including throughput time, product blocked time, product earliness, product lateness and machine utilization. Abdi [18] addressed the selection of layout configurations at the design stage. The indicators taken into account are related to layout reconfigurability, cost, quality and reliability. In [5], the author addressed the equipment selection problem and considered indicators related to manufacturing reconfigurability, cost, quality and performance. Later in [6], the author integrated two other types of indicators related to inventory and operators. Inventory indicators are related to the inventory of raw material, work in process and final products, which are different from one configuration to another. Operator related indicators evaluate the operator skills acquired by training services. These skills can help to cope with configuration changes and are considered as a key factor for a successful reconfiguration of the manufacturing system. Hasan et al. [24] suggested a performance indicator in terms of service level to assess the effort needed in the reconfiguration process. This indicator depends on a set of indexes related to the ability and ease to add, remove, re-adjust and reconfigure machines.

In the existing literature, we can notice that the indicators that were used are mainly related to the characteristics of equipment and/or products. The features considered in selecting configurations are almost exclusively technical and are related to the physical (hardware) component of the manufacturing system. None of these works considers aspects related to human factors and ergonomics. The working environment is considered safe and healthy, although worker activities in RMSs are expected to change frequently due to sustained work pace, which is stressful and can lead to errors and damages. In this respect, Elmaraghy et al. [25] propose a multi-attribute utility model to assess human errors based on task characteristics, work environment and worker capabilities. El dardiry et al. [26] investigate the level at which machine usability (a concept that tries to evaluate how easy it is for a human operator to interact with, use, monitor or supervise a machine) contributes to the flexibility and the dynamic changeability of an RMS. They address the equipment reconfigurability and usability under different environmental working conditions. The difficulty of tasks and workplace ergonomics are considered as attributes, which are evaluated by utility functions. Although the impact of work environment is highlighted in RMSs, these articles focus on modeling the factors that may affect product and process quality performances. Unfortunately, the arduous working factors that affect workers and so, strongly influence the decision-making process are not addressed. Our suggestions intend to fill in this gap by incorporating human factors and ergonomics related aspects in the decision making process.

III. Human Factors Related Indicators for Reconfiguration

In manufacturing systems, some work conditions are arduous (cf. Table 1) and can lead to serious occupational health and safety issues [11]–[14]. In this context, companies have developed mechanisms and governments adopted regulations to take care of human factors in industrial organizations. Companies are making sustained efforts to adopt standards that demonstrate sound occupational health and safety practice and performance, such as the BS OHSAS 18001 standard, which is the internationally recognized assessment specification for occupational health and safety management systems [27]. Legislation authorities established labor codes and regulations that insure safe and healthy working conditions. Such regulations and mechanisms aim at anticipating and preventing exposure to working risk factors that can lead to perpetual effects, identifiable and irreversible on health, as it is for example the case of the French Labor Code, which dedicated its section L.4121-3-1 to define work arduousness. Table 1 presents some working risk factors as they are defined in section D. 4121-5 of the French labor code.

However, in spite of these efforts, the link is still weak between the recommendations of such regulations, codes and standards, and approaches that enable advised decision making about how to design and manage work environments in such a way that satisfies those regulations, codes and standards, and insures their application [12]–[14]. In his thesis, Zelano [13], who is a French physician specialized in the medicine of work, focused on enumerating, defining and quantifying the factors that make work arduous. His objective was to suggest a methodology that enables decision-makers satisfy their legislative responsibilities and meet the required regulations. The methodology focuses on diagnosing factors of arduousness of work. It does not provide insights on how to use the suggested quantifications to evaluate possible work environments and configurations. Based on the definitions of Table 1 and on the work of Zelano [13], our work intends to fill in (at least part of) this gap by suggesting some indicators, namely musculo-skeletal trouble (*MST*), Repeatability (*R*) and Noise (*N*), to evaluate available configurations and take work arduousness into account while reconfiguring manufacturing systems. The following indicators were designed by Zelano [13] for medical purposes, applications and concerns. Our contribution consists in adapting them and in using them in the configuration evaluation and selection problem.

TABLE 1. ARDUOUS FACTORS OF WORK AS DEFINED BY FRENCH LABOR CODE.

Type of factor	**Example of factor**
Prominent physical constraints	-Manual handling charges (Section R.4541-2) -Painful positions defined as forced positions of the joints -Mechanical vibrations (Section R.4441-1)
Aggressive physical environment	-Hazardous chemical agents (Sections R.4441-12 and R.4441-60), including dust and smoke -Activities performed in a hyperbaric environment (Section R.4461-1) -Noise (Section R.4431-1) -Extreme temperatures
Pace of work	-Night work in certain conditions (Sections L.3122-29 to 3122-31) -Working in alternating successive teams -Repetitive work: repetition of the same gesture with a constrained rate, imposed or not by an automatic displacement of pieces or by piecework remuneration, with a defined cycle time.

A. *Musculo-Skeletal Trouble (MST) indicator*

The musculo-skeletal trouble to which a worker may be exposed when working in a given configuration is based on six risk factors related to tasks, which are intensity of tasks (I), duration of effort (DE), number of efforts per minute (E), posture (P), work speed (S) and duration of task (DT). Each of these factors presents five levels to which different coefficients are assigned. Table 2 shows for each level of risk factor the corresponding coefficient as it was introduced in [13].

TABLE 2. EVALUATION OF MST RISK FACTORS [13]

Intensity		Duration of effort (% cycle)		Number of Efforts/ min		Posture		Speed		Duration of task (h)	
Level	*C(I)*	Level	*C(DE)*	Level	*C(E)*	Level	*C(P)*	Level	*C(S)*	Level	*C(DT)*
Light	1	<10	0,5	<3	0,5	Very good	1	Very low	1	<1	0,25
A little Hard	3	10-29%	1	4-8	1	Good	1	Low	1	1-2	0,5
Hard	6	30-49%	1,5	9-14	1,5	Medium	1,5	Medium	1	2-4	0,75
Very Hard	9	50-79%	2	15-19	2	Bad	2	Fast	1,5	4-8	1
Close to max	13	>80%	3	>20	3	Very bad	3	Very fast	2	>8	1,5

The MST indicator for an operator is given by multiplying the coefficients of the risk factors according to equation (1):

$$MST = C(I)*C(DE)*C(E)*C(P)*C(S)*C(DT) \qquad (1)$$

Where C(x) is the coefficient related to risk factor x. A high MST indicator shows that the associated configuration has a high risk of musculo-skeletal trouble. A high MST can cause some diseases that affect muscles, such as muscle and lower back pains, thus leading to work accidents, sickness leaves, etc. When several configurations are available, the decision maker should choose the alternative that has the lowest associated MST.

B. *Repeatability indicator*

The repeatability (N) of tasks is given by an assessment scale presented in Fig. 1 [13]. According to the description of the task, N is given a value within the interval [0-10]. A high repeatability indicator may generate detrimental effects, such as stress, low morale, high rates of accidents, damage to equipment or products, etc. When several configurations are available, the decision maker should choose the alternative that has the lowest associated repeatability indicator.

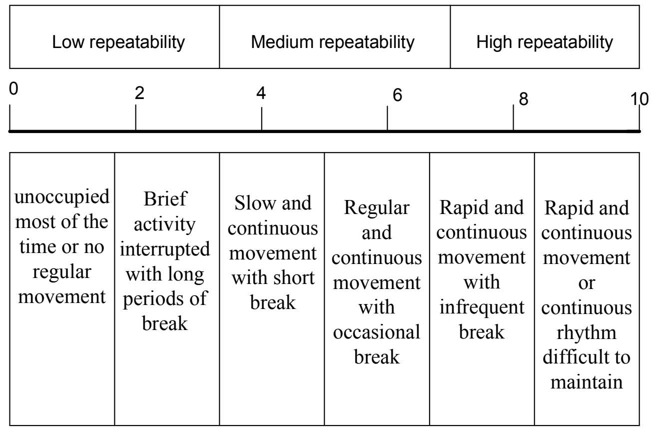


Fig. 1. Assessment scale of repeatability [13].

C. *Noise indicator*

Noise is a vibration that propagates through the air and that can be characterized by its intensity (In), frequency (F), level of acoustic pressure (AP) and duration (D) [13]. It causes an auditory sensation that can be dangerous if the level is excessive. We develop a scale to measure the noise indicator (N) as shown in Table 3. The level of noise exposure is compliant with the labor regulation fixed at maximum 87dB for intensity and 137dB for acoustic pressure peak level.

TABLE 3. EVALUATION OF NOISE RISK FACTORS.

Intensity (dB(A))		Frequency (HZ)		Acoustic Pressure(dB(C))		Duration (h)	
Level	*C(In)*	Level	*C(F)*	Level	*C(AP)*	Level	*C(D)*
0-29	0-3	20-200	0-2	0-49	0-3	>0,5	0-3
30-59	3-5	200-2000	3-5	50-99	3-5	0,5-2	3-5
60-79	5-7	2000-20000	5-7	100-129	5-7	2-4	5-7
80-86	7-10	>20000	7-10	130-136	7-10	4-8	7-10

The N indicator of a configuration is calculated according to equation (2):

$$N = C(In)*C(F)*C(AP)*C(D) \qquad (2)$$

Where C(x) is the coefficient related to noise characteristic x. A high noise indicator shows that the related configuration presents a high risk of noise. When several configurations are available, the decision maker should choose the alternative that has the lowest associated noise indicator.

IV. AN AHP TO EVALUATE AND SELECT CONFIGURATIONS

In RMS, moving from one configuration to another is a complex decision problem that requires the evaluation and selection of a configuration among several available alternatives based on various criteria that are often antagonistic, time-varying and not having the same importance. To assess and rank available alternative configurations, a multi-criteria decision-making approach is needed. As it was introduced in section II, several multi-criteria approaches are available and can be used to tackle this problem. Each approach has its advantages and its limitations. In our case, we would like to rely on the expertise and knowledge of decision makers to evaluate and select configurations based not only (and exclusively) on performance, but also on work arduousness considerations. As decision makers may have subjective preferences and individual points of view that vary from one person to another and from a manufacturing system to another, we choose the AHP because it relies on pairwise comparisons, which make it easier and more straightforward for decision makers to express their preferences. AHP allows dealing with the complex structure of the configuration selection problem by decomposing it through a hierarchical process. The relative importance of each alternative configuration is obtained through pairwise comparisons. The AHP provides mechanisms to ensure coherence of preferences. We do not contribute to the AHP method itself, but instead, we use it to consider factors that were not considered before in the configuration evaluation and selection problem. These are the main reasons and advantages that make us choose AHP rather than another multi-criteria ranking approach, although other choices are still available and worth consideration.

A. General architecture

The suggested AHP model is structured according to different levels. At the highest levels, the suggested model relies on strategic and operational criteria that are generic and suitable for a wide range of manufacturing companies. At lower levels, the suggested model involves sub-criteria and indicators that are more specific and that must be adapted according to the specific needs and conditions of work of the company. For example, in chemical industries, we can consider human indicators related to the exposition to hazardous chemical agents, whereas in manufacturing industries, attention is more focused on avoiding heavy loads or noise. As the importance of each criterion may differ from one configuration to another, and the importance of each configuration may differ from one criterion to another, the criteria and configurations must be precisely ranked by the decision maker based on a scale that is given by [16] and illustrated in Table 4.

TABLE 4. EVALUATION SCALE [16].

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values, 1.1, 1.2, etc. for elements that are very close in importance		

The proposed AHP is based on the main following steps.

-Step1: Define the retained indicators and alternatives.
-Step2: Determine weights of criteria, sub-criteria and indicators through pairwise comparisons.
-Step3: Evaluate the Criteria Consistency Ratio (CR_C).
-Step4: If CR_C is acceptable (CR_C<10%) then go to step 5, else go to step2.
-Step5: Determine the preferences of configurations.
-Step6: Evaluate the Configuration Consistency Ratio (CR_F).
-Step7: If CR_F is acceptable (CR_F<10%) then go to step 8, else go to step 5.
-Step8: Compute the score of each configuration.
-Step9: Rank configurations in descending order according to their scores.
-Step10: Select the first ranked configuration.

The hierarchical framework of the problem under study is shown in Fig. 2.

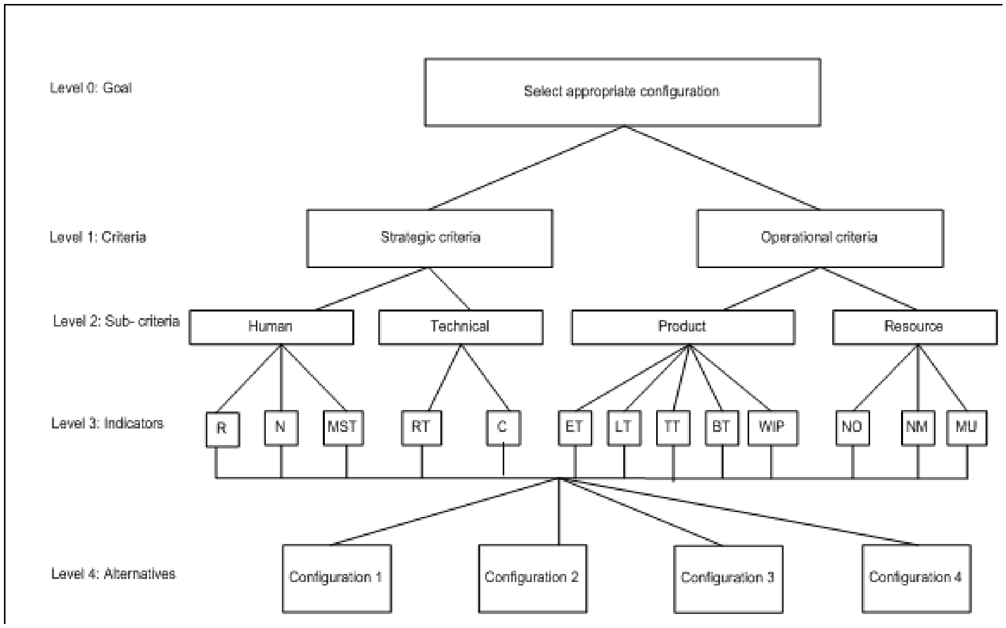


Fig. 2. The AHP structure for the studied problem.

B. Strategic criteria, sub-criteria and indicators

Strategic indicators involve human factor related indicators and technical indicators that quantify the capacity of the system to evolve from one configuration to another. Such indicators reflect the intrinsic characteristics of the system, and should include measures that reflect its modularity, convertibility, diagnosability, scalability and customization.

1) Human factors related indicators

We suggest integrating some human factor related indicators to describe available configurations of the manufacturing system. Each available configuration is described by specific values of MST, Repeatability (R) and noise (N). Each indicator is proper to each configuration and depends on the configuration parameters (type and number of machines; duration of task, nature of task, posture of operator, rate of production; intensity of noise generated by machines).

a) Musculo-Skeletal Trouble

For each configuration, the MST_O of each operator O is evaluated according to Table 2 and Equation (1) of section III.A. The MST of a configuration (MST_{conf}) is the mean value of MST_O for the set of operators assigned to the configuration. MST_{conf} is calculated according to Equation (3):

$$MST_{conf} = \sum_{i=1}^{n} \frac{MST_{oi}}{n} \quad (3)$$

Where n is the number of operators engaged in the configuration

b) Repeatability

For each configuration, the R_O of an operator O is evaluated according to the scale shown in Fig. 1 of section III.B. The repeatability indicator (R_{conf}) of a configuration is the mean value of R_O for the set of operators assigned to the configuration. R_{conf} is calculated according to Equation (4):

$$R_{conf} = \sum_{i=1}^{n} \frac{R_{oi}}{n} \quad (4)$$

Where n is the number of operators engaged in the configuration

c) Noise

The intensity, the frequency and the acoustic pressure of noise of machines are given by the machine builder. The noise N_m of each machine m is calculated based on Table 3 and Equation (2) of section III.C. The noise indicator (N_{conf}) of a configuration is the sum of N_m for the set of machines assigned to the configuration. N_{conf} is calculated according to Equation (5):

$$N_{conf} = \sum_{i=1}^{k} N_{mi} \qquad (5)$$

Where k is the number of machines involved in the configuration

2) Technical indicators

Two technical indicators are considered: reconfiguration time and convertibility.

a) Reconfiguration Time

The reconfiguration time $RT_{(i,\,j)}$ is the time needed to move from the current configuration i to a new configuration j. It is given by Equation (6):

$$RT(i,j) = TIR\ (i,j) + TCB(i,j) \qquad (6)$$

Where:

TIR is the time needed to introduce or to remove a machine or a buffer.

TCB is the time required to adjust the capacity and the location of storage buffers. In fact, as it will be described in more details in the case study section, we consider two types of buffers, namely small and large capacity buffers. Each type of buffer is characterized by capacity and location requirements.

The reconfiguration time $RT(i)$ of a configuration i is computed according to Equation (7):

$$RT(i) = \sum_{j=1}^{n} RT(i,j) \qquad (7)$$

Where n is the number of configuration and j=1,..n ; i=1,..n

The estimated reconfiguration times are given in Time Units (TU), we propose to each reconfiguration task the corresponding reconfiguration time as shown in Table 5.

TABLE 5. TIMES REQUIRED FOR RECONFIGURATION TASKS.

Reconfiguration tasks	**Reconfiguration times (TU)**
Insert a machine or a small buffer	10
Remove a machine or a small/large buffer	7
Transform large capacity buffer into small capacity buffer	5
Transform small capacity buffer into large capacity buffer	3

b) Convertibility

Convertibility is defined as the capability of a system to adjust production functionality, or to change from one product to another. Speredelozzi et al. [28] suggested measuring the convertibility C of a system based on a score calculated according to a questionnaire that quantifies the perception of a decision maker of how easy it is to adapt the system functionality. System convertibility C includes concerns related to machines, their arrangements, and material handling devices. These factors are combined in Equation (8) for an overall intrinsic assessment of system convertibility.

$$C = w_1 C_c + w_2 C_M + w_3 C_H \qquad (8)$$

Where w_1, w_2, and w_3 are weights attributed to convertibility factors and adjusted according to decision maker preferences. C_c, C_M, and C_H, are convertibility metrics associated respectively with the configuration, machine, and material handling system, calculated as suggested by Speredelozzi et al. [28].

C. Operational criteria, sub-criteria and indicators

Operational indicators are based on criteria that are related to the dynamic behavior of the system and involve product related indicators and resource related indicators. These indicators can generally be evaluated using simulation models [19] constructed using discrete event simulation software, such as ARENA, ProModel, Witness, etc.

1) Product indicators

As in [7], product related indicators include the throughput time (*TT*), the product blocked time (*BT*), the product earliness (*ET*), the product lateness (*LT*), the machine utilization (*MU*) and work in process (*WIP*). These indicators are evaluated using a simulation model that is run on ARENA discrete event simulation software.

a) Throughput Time

The throughput time TT_P of a product *P* is the period required for a single product *P* to be manufactured.

$$TT_P = C_P - ST_P \qquad (9)$$

C_P and ST_P are respectively the completion time and the start time of the product *P*. The system throughput time *TT,* is the mean of TT_P for the set of products manufactured in the system.

b) Product Earliness

The product earliness ET_P is computed when the product *P* is completed before its Due Date (DT_P) as follow:

$$ET_P = DT_P - C_P \qquad (10)$$

The system earliness given by indicator *ET* is the mean of ET_P for the set of products that manufactured in the system.

c) Product Lateness

The product lateness LT_P is computed, when the product *P* is completed after its Due Date (DT_P).

$$LT_P = C_P - DT_P \qquad (11)$$

The system lateness *LT*, is the mean of LT_P for the set of products manufactured in the system.

d) Product Blocked Time

The product blocked time is the duration elapsed from the moment when the product *P* arrives at the machine queue and waits until loaded on the machine to be processed. It is noted (BT_P). The total blocking time of the system *BT*, is determined by calculating the mean of BT_P for the set of products manufactured in the system.

e) Work In Process

The work in process is the set of unfinished items for products in a production process. These items are not yet completed but either just being fabricated or waiting in a queue for further processing or in a buffer storage.

2) Resource indicators

Resource indicators are related to machine utilization, number of machines and number of operators. The Number of machines NM and the number of operators NO are directly counted from the considered configuration.

a) Machine Utilization

The ratio (MU_K) indicates the extent of using the machine *K*. The system utilization *MU* is the mean of MU_K for the set of machines that are used in the system.

b) Number of Machines

The number *NM* of machines indicates how many machines are used in a configuration.

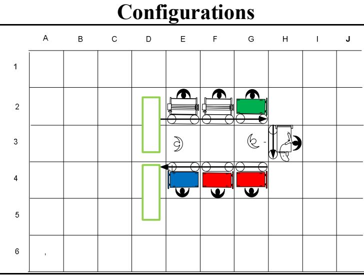
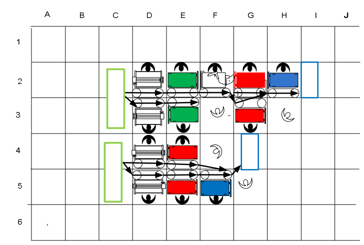
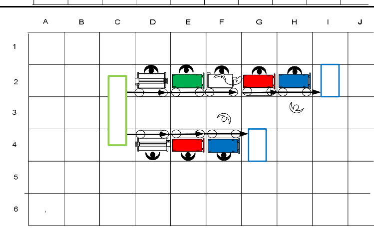
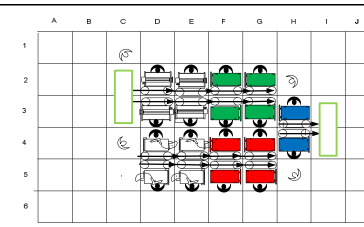
c) Number of operators

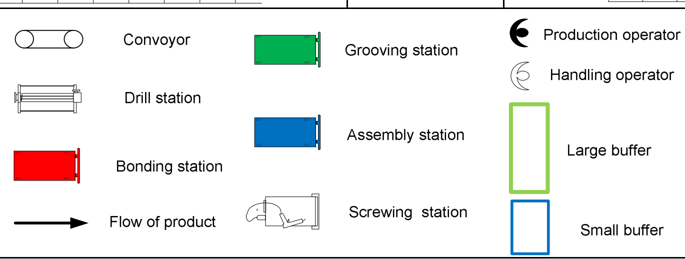
The number *NO* of operators indicates how many operators are used in a configuration.

V. CASE STUDY

We consider a manufacturing system with 18 machines and 6 storage buffers. Two types of products (A and B) are manufactured according to different process plans. The product of type A requires three elementary operations (drilling, bonding, and assembly). The product of type B requires five elementary operations (drilling, grooving, screwing, bonding, and assembly). For each operation of drilling, screwing, bonding and grooving, four machines are available. But for assembly, only two machines exist. The plant floor is represented as a grid of 6 rows (labelled numerically from 1 to 6) and 10 columns (labelled alphabetically from a to j). A location is an intersection of one row and one column. Workstations and storage buffers are assigned to locations. A workstation is a set of a machine and a conveyor. One workstation is assigned to one location. Buffers are of two types: a large capacity buffer needs two locations, whereas a small capacity buffer needs only one location. A production operator is assigned to each workstation. As needed, a handling operator may (or not) be assigned to a configuration. Therefore, a configuration corresponds to a specific assignment of predefined numbers and types of workstations, buffers and operators to precise locations on the plant floor. Let us consider four available configurations, namely CON1, CON2, CON3, and CON4 as shown in Table 6.

TABLE 6. PRESENTATION OF THE AVAILABLE CONFIGURATIONS.

Notations	Configurations	Notations	Configurations
CON1		CON3	
CON2		CON4	



We assume that we are in exploitation phase and the workshop is currently organized according to configuration CON2 to satisfy a specific situation. At some point of time, a change of situation occurs, in which a new customer order of 70 units of type A product and 100 units of type B product have to be taken into account. So, a reconfiguration decision has to be made: should the decision maker continue producing with the current configuration (CON2) or should he/she reconfigure the system? If the system has to be reconfigured, which configuration should be chosen: CON1, CON3 or CON4?

The proposed AHP is developed and implemented according to section IV. Weights are given to each configuration of Table 6 based on pairwise comparison with respect to each indicator and according to the preferences of decision makers. Table 7 shows the preferences of a decision maker based on pairwise comparison of configurations. For example, when comparing CON1 to CON2 with respect to RT (cf. Equation 6), the decision maker prefers CON2 to CON1 with a level of preference equal to 4.

TABLE 7. DECISION MAKER CONFIGURATION PREFERENCES BASED ON PAIRWISE COMPARISON.

	RT		C		N		R		MST		NM		NO		MU		ET		LT		BT		TT		WIP	
	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref	Pref. Con.	Int. Pref
CON1/ CON2	CON2	4	CON2	3	CON1	3	CON2	2	CON2	2.2	CON1	3	CON1	3	CON1	1	CON2	2	CON2	9	CON2	2	CON2	2	CON2	3
CON1/ CON3	CON1	2	CON3	5	CON1	4.2	CON3	5	CON3	5	CON1	4.2	CON1	4.2	CON1	3	CON3	4	CON3	9	CON3	5	CON3	5	CON3	4
CON1/ CON4	CON1	6	CON4	6	CON1	7	CON4	7	CON4	7	CON1	7	CON1	7	CON1	5	CON4	6	CON4	9	CON4	7	CON4	7	CON4	8
CON2/ CON3	CON2	5	CON3	2	CON2	2	CON3	4	CON3	4	CON3	1.5	CON3	1.5	CON2	3	CON3	3	CON3	1	CON3	4	CON3	4	CON3	2
CON2/ CON4	CON2	9	CON4	5	CON2	3	CON4	6	CON4	6	CON2	3	CON2	3	CON2	5	CON4	5.8	CON4	1	CON4	6	CON4	6	CON4	6
CON3/ CON4	CON3	5	CON4	1	CON3	3.3	CON4	2	CON4	2.1	CON3	3.3	CON3	3.3	CON3	2.5	CON4	2	CON4	1	CON4	2	CON4	2	CON4	5

Based on decision maker preferences with respect to criteria, sub-criteria and indicators, the weights of criteria can be determined as shown in Table 8. For example, according to Table 8, the score of CON1 is obtained as: Score (CON1) =

0,5*0,5*0,5*(0,22+0,11)+0,5*0,5*(0,25*0,35+0,15*0,1+0,6* 0,1)+0,5*0,5*(0,35*0,37+0,35*0,37+0,3*0,35)+0,5*0,5* (0,35 *0,1+0,22*0,1+0,1*0,1+ 0,22*0,1+0,11*0,1)

TABLE 8. DECISION MAKER CRITERIA PREFERENCES AND EVALUATION OF CONFIGURATIONS BASED ON DEFINED CRITERIA.

	Strategic criteria weight = 0,5					Operational criteria weight = 0,5							
	Technical weight = 0,5		Human weight = 0,5			Resource Weight=0,5			Product Weight=0,5				
	RT	*C*	*N*	*R*	*MST*	*NM*	*NO*	*MU*	*ET*	*LT*	*BT*	*TT*	*WIP*
Indicator weight	0,5	0,5	0,25	0,15	0,6	0,35	0,35	0,3	0,35	0,22	0,1	0,22	0,11
CON1	0,22	0,11	0,35	0,1	0,1	0,37	0,37	0,35	0,1	0,1	0,1	0,1	0,1
CON2	0,5	0,2	0,3	0,14	0,13	0,25	0,25	0,35	0,12	0,3	0,14	0,14	0,2
CON3	0,2	0,34	0,25	0,36	0,37	0,26	0,26	0,2	0,38	0,3	0,36	0,36	0,3
CON4	0,08	0,35	0,1	0,4	0,4	0,12	0,12	0,1	0,4	0,3	0,4	0,4	0,4

A. Simulation without considering human factor related indicators

As shown in Fig. 3, if we do not take human factor related indicators into account, CON2 is the most appropriate configuration, which means that production should continue using the same current configuration, and that no reconfiguration is needed. It can be seen that CON2 (weight 0.302) is preferred to CON3 (weight 0.282), CON3 is preferred to CON4 (weight 0.23), which in turn is preferred to CON1 (weight 0.198). Overall *CR* is 6% (<10%).

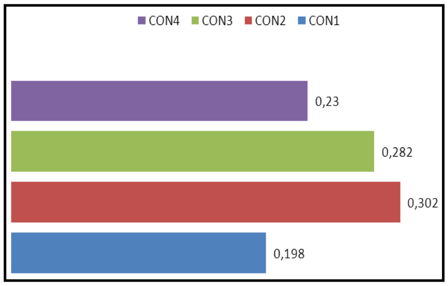


Fig. 3. Configuration evaluation without human factor related indicators.

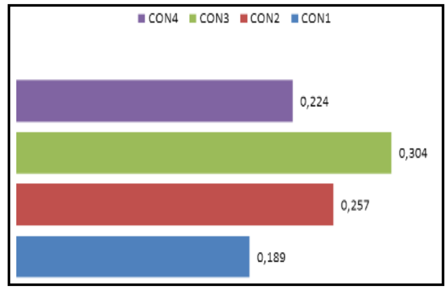


Fig. 4. Configuration evaluation with human factor related indicators.

B. *Simulation considering human factor related indicators*

Fig. 4 shows that CON3 is the top ranked configuration (weight 0.304), followed by configuration CON2 (weight 0.257), then configuration CON4 (weight 0.224). Finally, configuration CON1 is the worst one with overall weight 0.189. The Overall CR is 6.5% (<10%). To explain why configuration CON3 is better than configuration CON2 when the human factor related aspect is taken into account, Fig. 5 shows the evaluation of each configuration according to N, R and MST indicators as they were computed in Table 8. CON3 dominates CON2 with respect to preferences of the decision maker and the weights attributed to the different criteria. Therefore, CON3 reduces the MST risk and offers healthier working conditions.

With respect to technical indicators, CON3 is the best alternative (cf. Fig. 6). For resource criteria, CON1 is the best alternative (cf. Fig. 6). CON1 and CON2 need fewer operators than CON3. However, this benefit has a negative impact on the human factor related aspect, since the workload per operator is greater and therefore health issues are more important. For product related criteria, Fig.6 shows that CON4 is preferred to CON3. It is interesting to note that CON3 is not too far from CON4, and it is far better than CON2 and CON1.

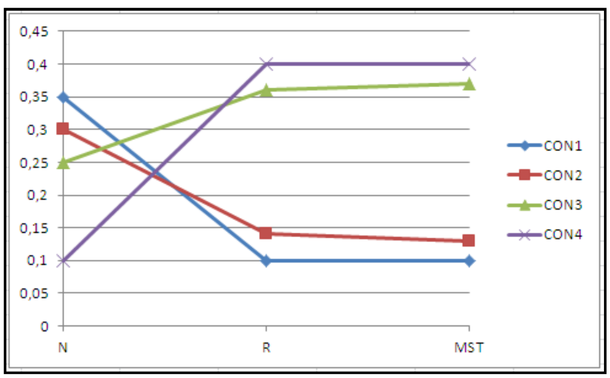


Fig. 5. Comparison of configurations based on the evaluation of human factor related criteria.

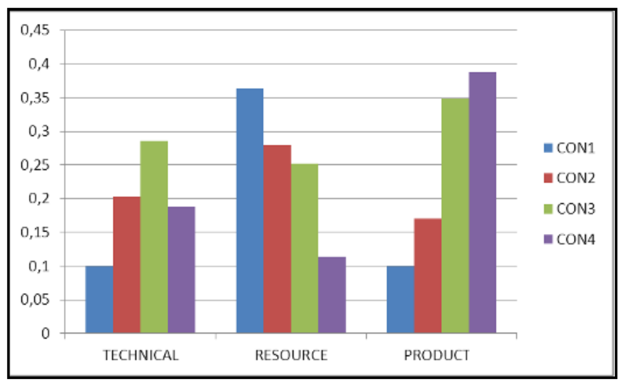


Fig. 6. Comparison of configurations based on the evaluation of technical, resource and product criteria.

From simulation results, it appears that AHP allowed taking into account human factor and ergonomics related concerns in the evaluation of available alternatives. It also enabled the selection of configuration CON3 as a configuration that offers an acceptable trade-off between conflicting technical, human resource and product related performance criteria.

VI. CONCLUSION

In this article, an AHP based approach is used to assist decision makers in reconfiguring an RMS. Contrarily to existing approaches, the suggested evaluation process does not focus on technical aspects only. It also integrates human factor related considerations. When dealing with realistic problems, assumptions like the workplace is safe and healthy or like workers are highly motivated, committed and productive, cannot generally be accepted. Indeed, arduous working conditions involve sickness, low productivity, stress and rejection by employees, etc., and thus, should be taken into account in decision-support systems. In this respect, we have investigated and proposed human factor and ergonomics related indicators to consider work arduousness when reconfiguring a manufacturing system. These indicators include a Musculo-Skeletal Trouble indicator related to prominent physical constraints, a Noise indicator to deal with aggressive physical environment and a Repeatability indicator related to the pace of work. These indicators are taken into account in addition to technical indicators to assess the competitiveness of the available configurations. The simulation results show the importance of considering such human issues. Indeed, selecting a configuration that satisfies only products and machine performances lead to a configuration that is not safe and healthy. Large values of musculo-skeletal trouble and repeatability can involve accidents or sick leaves which negatively impact on the expected performances. Further works should consider other features, like environmental requirements, to approach the global performance.

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