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A Few Descriptive and Optimization Issues on the Material Flow at a Research-Academic Institution: The Role of Simulation

D. R. Delgado Sobrino, P. Košťál, and J. Oravcová

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Abstract**—**Lately, significant work in the area of Intelligent Manufacturing has become public and mainly applied within the frame of industrial purposes. Special efforts have been made in the implementation of new technologies, management and control systems, among many others which have all evolved the field. Aware of all this and due to the scope of new projects and the need of turning the existing flexible ideas into more autonomous and intelligent ones, i.e.: Intelligent Manufacturing, the present paper emerges with the main aim of contributing to the design and analysis of the material flow in either systems, cells or work stations under this new "intelligent" denomination. For this, besides offering a conceptual basis in some of the key points to be taken into account and some general principles to consider in the design and analysis of the material flow, also some tips on how to define other possible alternative material flow scenarios and a classification of the states a system, cell or workstation are offered as well. All this is done with the intentions of relating it with the use of simulation tools, for which these have been briefly addressed with a special focus on the Witness simulation package. For a better comprehension, the previous elements are supported by a detailed layout, other figures and a few expressions which could help obtaining necessary data. Such data and others will be used in the future, when simulating the scenarios in the search of the best material flow configurations.

Keywords**—**Flexible/Intelligent Manufacturing System/Cell (F/IMS/C), material flow/design/configuration (MF/D/C), workstation.

I. INTRODUCTION

IN the past years it has been seen a quite huge evolution from conventional manufacturing systems to a more flexible and intelligent manufacturing. These still rather emerging FMS are capable of processing different types of products in an arbitrary sequence with insignificant setup delays between operations, and are mainly distinguished from other types of manufacturing systems by the following characteristics: high degree of functional integration, complex tool management and complex control software. Such systems as well all their most modern fellows, e.g.: Intelligent, Holonic, Agent-Based MS are relatively expensive and thus and even when it is becoming better over the years, just a few companies can get to their implementation. As for solving these cost matters, a growing tendency to only develop and use smaller versions, e.g. I/FMC, is taking place either with real life production intentions or as research projects helping to evolve the field, [1]-[4].

The IPSAM consists of several facilities where more intelligence needs to be implemented, i.e.: a pneumatic laboratory, see Fig. 1 taken from MTF STU archives, a flexible manufacturing cell, see Fig. 2, and second laboratory where pick and place operations and assembly-disassembly processes are carried out see Fig. 3 taken from [9]. The pneumatic laboratory is part of a current cooperation with the company FESTO, while the second one and the cell itself belong to research projects and most of the devices despite having been acquired from the same company, were designed at the institute according to the projects' goals. All of these facilities are also motivated by/or intended to help the educational process, e.g.: besides the constant interaction of the students with them and their use in the classes and diploma thesis, there is also a virtual laboratory project being developed which is supposed to allow students to virtually create programs and then, either via internet or USB make them run in the own devices; for the time being this is already possible with an ABB robot IRB 120 recently acquired at the institute. Despite the many advances, at present all of these facilities and associated ideas are still subject for further improvements and under a constant changing process, towards a more intelligent, evolved and autonomous conception. Some of the changes related to such migration already encompassed most of the design and acquisition of new needed devices, and are currently being mainly focused in the design, analysis and projection of the material flow and the interconnection of most of the independent parts.

D. R. Delgado Sobrino, P. Košťál, and J. Oravcova are with the Institute of Production Systems and Applied Mechanics, Faculty of Material Sciences and Technology (MTF), Slovak University of Technology (STU), Trnava, Slovakia, (e-mail: daynier_sobrino@stuba.sk, peter.kostal@stuba.sk, jarmila.oravcova@stuba.sk).

Fig. 1 Pneumatic Laboratory in cooperation with FESTO Source: MTF STU archives

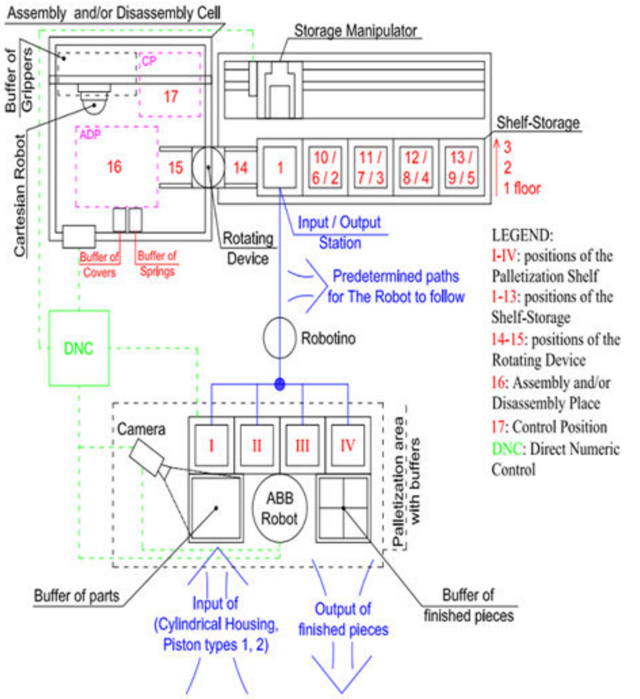

Fig. 2 Detailed Layout intended for the IMC Source: Self-elaboration

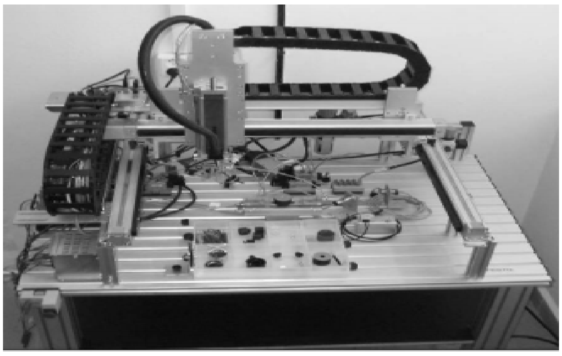

Fig. 3 Cartesian robot station for the operations of assembly-disassembly [9]

II. INTELLIGENT MANUFACTURING

Even when many authors have described what IM is, the term has evolved over time and not all the definitions concrete the modern meaning of such philosophy. However, the following one that fits most of the modern ideas: "IM is manufacturing, with the minimum of human intervention, by equipment in which is embedded the skills and knowledge of manufacturing experts so that the products produced are indistinguishable from those produced in conventional manufacturing systems and with similar levels of output and utilization of raw materials and energy. This previous definition clearly describes some of the characteristics and goals of the projects at the IPSAM and thus, some of the objective of this paper. On the other hand, Fig. 4 shows what intelligence implies in a MS and some of the methods supporting its functioning in relation with the systems themselves and the society. These concepts also apply to F/IMC and other smaller subsystems, e.g.: stations like the one showed in Fig. 3.

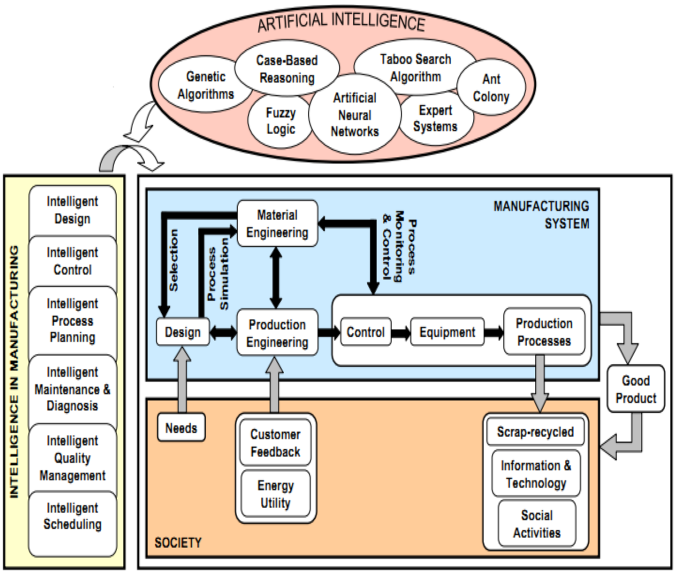

Fig. 4 Overview of the IM and some associated methods in connection with the MS and the society [10]

III. A FEW USEFUL PRINCIPLES FOR THE MATERIAL FLOW DESIGN

1. There must be predetermined paths among the devices and these must be as close as possible
2. The Input/ Output (I/O) position(s) of the pieces and parts to a system, cell, workstation, etc., should remain free if possible
3. Empty movements of the AGV, conveyors, etc. should tend to 0
4. Manipulations, rotations or any other movement should be reduced so that less energy and time are used as well as less complexity added
5. An AGV should not wait for a part being assembled when having other stored items ready to be moved
6. Manipulators should never wait for a part coming with

AGV, if having available stored parts to manipulate

7. The speed of the devices should tend to the maximum always that the quality remains good
8. The MF must be as simple and linear as possible
9. The computer controller and the dependent devices must collaborate so as avoid unnecessary movements and anticipate some actions, e.g.: an AGV mustn't take a piece towards an I/O when there will be a collision and it would have to take it back. Elements of intelligence like these are intended to be added at the IPSAM.
10. Some positions should be kept free as for relocation purposes and avoidance of collisions
11. The position an AGV takes the pallet, pieces, parts from should be kept available so that when it comes back at any AGV outgoing movement w ($\mathrm{AGVOM_w}$), there is a free position to place. By preference and under the concept of reducing variability, it is desired to keep such same position, however, in case there are more positions and there is another finished piece to dismount, e.g.: any other of the 4 positions of the palletization area with buffers in Fig. 1, then the position AGV took the pallet from could be optionally occupied since there will be a free position anyway. Notice that $\mathrm{w} = \overline{1, \mathrm{o}}$ and can be also referred to as the number of empty travels (eps) plus the number of finished pieces (fpc) returned back from a certain workstation to a storage/buffers area. Then, if $\mathrm{AGVOM_w}$ takes one and only one pallet, back, and that $\mathrm{s} = \overline{1, \mathrm{l}}$ and $\mathrm{c} = \overline{1, \mathrm{d}}$, it can be stated that:

$$\mathrm{AGVOMw} = \mathrm{ep_S} + \mathrm{fp_c} \tag{1}$$

The last expression, if considering the number of pieces of bad quality, let us call them by Fp, where $\mathrm{p} = \overline{1, \mathrm{q}}$, and also knowing the value of eps, could be turned out to obtain the Throughput (T) of the system, cell or workstation at any time t, i.e.:

$$\mathrm{T} = \mathrm{ROM_w} - \mathrm{F_p} - \mathrm{ep_S} \tag{2}$$

Despite most of the principles are proper from this paper, it was useful to analyze some rules, see 7 and 8, from [3], as well as the whole paper itself of [6].

IV. ANALYSIS OF ALTERNATIVE SCENARIOS

In the process of analysis ofa F/IMC/S (commonly more complex than in a single workstation), it is usually important to avoid being stuck in local optima during the optimization of the MF or any of the associated problems, e.g.: the scheduling, transport and inventory ones among others. Each one of these problems and specially the MF one could be defined a number of general scenarios, besides the first/initial one, and even sub-scenarios to be further explored and taken into account, what could possible become a combinatorial problem. The following elements are useful while defining such alternative scenarios:

1. To consider time buffers among some of the devices of the system, cell or workstation based on the principles of the theory of constraints
2. To change the I/O stations to a different place
3. To change the capacity of the buffers, etc.,
4. To combine several or all the changes made on the original/initial scenario.

As mentioned, each one of these variants could also generate others, e.g.: regarding the possible different operating speeds assumed for each resource, their combinations and even regarding the prioritizations of the material flow for a certain order or batch, among others. This way, even when not being in the most complex of the cases, the problem presents itself as a combinatorial one which are usually non-polynomial-hard (NP-hard), meaning that the time required to find the optimal solution, increases exponentially as the problem size increases linearly. For this, the use of heuristics, metaheuristics or even approximation approaches are worth taking into account and thus find a nearly optimal solution without the use of excessive time and computational resources.

Related to all this, (3) which has a great value of use when analyzing the most basic combinatorial problems, is a good starting point to get to another one that in future papers, helps determining the total number of scenarios or combinations to be explored and compared in some of the systems/cell or stations at the IPSAM. Such future expression will be used for each original scenario initially identified, so that, either making vary one of its elements, i.e.: devices of a system, cell or workstation, through all its possible discreet values or, several devices at the same time, the number of combinations derived from each original scenario, let us call them sub-scenarios, can be determined. Notice that the term sub-scenario will be just used to indicate where they come from, at the end each of them will be assumed as a another configuration of the system, cell or workstation to be further simulated and analyzed in the search of a better material flow.

$$C(n,k) = \binom{n}{k} = \frac{n!}{(n-k)!k!} \tag{3}$$

where n: total number of scale values that the elements of system, cell or workstation (devices) being searched for combinations, have together in their discreet or discretized varying scales; k: number of varying devices being searched for combinations

However, despite the previous expression offers all the combinations and give an insight on what must be calculated, it does not distinguish between the combinations inside the same set and those among sets, being just the last ones which are needed and possible, given the characteristics of the problem and goal of this research, i.e.: it is neither possible nor logical to have at the same time 1 device operating at 2 or more different speeds. To help discerning on this inconvenience, it is useful to have a look into the pair-wise combinations field which fits part of the research needs of strictly searching among different sets. Similarly, the graph theory and specifically the complete bipartite graph problem help also understanding the nature of the needed future expression and how to get to its final formulation; from its perspective, each pair of sets, e.g.: two machines being searched for combinations, must be simply seen as complete bipartite graph, see Fig. 5.

However, these theories themselves do not exactly match or totally cover the requirements of our needed expression, and as in most of the practical applications, either some modifications should be made to let them fit or they can just be used to partially address the problem. From these analyses, the authors allow themselves to decide on a final expression to be proposed in future work.

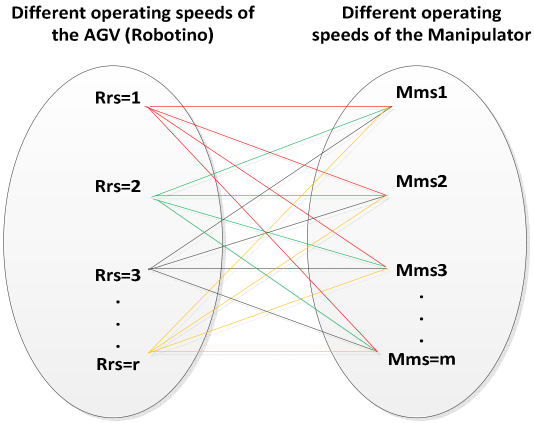

Fig. 5 A complete bipartite graph used for obtaining the number of combinations between two devices of a MS based on their speeds
Source: Self-elaboration

where Rrs: operating speeds of an AVG robot, $Rrs = \overline{1, r}$ and Mms: operating speeds of a Manipulator (M), $Mms = \overline{1, m}$

V. General Possible States of a System, Cell or Workstation

With respect to the MF, systems, cells or workstations could be empty, with remaining capacity, full but not under collision, under collision and interrupted. These could be full but not under collision, always that being full most of the positions, let us say pallets of a system like the one shown in Fig. 1, there is still a defined number of safety empty pallets to be used. Otherwise a collision could occur. The system, cell or workstation may be under collision when (1) it is not possible at any AGV incoming movement (AGVIM) to place parts in an I/O since this is full by any relocation process, this could be solved if existing at least more empty positions (safety or not), among the devices where a relocation could executed, otherwise the collision remains. Other possibilities of collision are: (2) being empty an I/O station, there are no other empty spaces to push a piece/part forwards, and (3) at any $AGVOM_w$, all the positions where the loaded piece should be placed are full. All of these possibilities even when mentioned are supposed to be stopped from happening if the system executes and follows the principles and thus acts and reacts intelligently. There is an interruption when by any circumstance and without a collision, this is not running. The interruptions can be partial, planned, not planned, and casual or due to other reasons.

VI. Simulation for the Design, Analysis, Control and Optimization of the Material Flow

Very often, software-based simulations, either using a common purpose simulation language, e.g.: SIMAN, SLAM or GPSS or a simulation tool package, e.g.: Arena, Promodel, Witness, etc., tend to model FMS/C, IMS/C or single workstations, as a set of interconnected queues, in which a workstation or device of it is represented by a single-stage service facility with an input/output queue. The material handling system is usually considered as a resource for which these workstations compete. The load/unload stations, although depending on the type of layout, are generally at the entrance and exit of the simulation model. In such a network of queues, parts are customers and it is the dispatching rules in the production schedule, which determine how to route them to the next machine. From the viewpoint of flow, a part is simulated as being either in a waiting, transporting, processing or controlling state in the system. Within a FMS/C unlike other production systems/cells, the part might be transported to any capable workstation at some decision points depending on such dispatching rules. In the case of an IMS, this event could occur similarly but however, some degree of uncertainty could be expected since the system would be supposed to perform operations in a more open and autonomous way.

Regardless of the case simulation functions as an interface to the physical system trying to capture its current status and thus works as a feedback for continuously improving the performance. Simulation can not only deal with the current states of the system, but also with the future uncertainties by randomly generating the future disturbances or according to a probability of future disturbances estimated from the past history. It can also be used to shorten any kind of long term evaluation or testing process, and to validate new designs, technologies or changes regarding the physical elements of the systems based on the model results [5]. This makes the mean time among proposals or designs, their correction and the complete implementation, shorter and less risky.

Table I presents a summary of some advantages and disadvantages of simulation in F/IMS/C:

TABLE I
USE OF SIMULATION IN FMS AND IMS

ADVANTAGES	DISADVANTAGES
It explore and analyzes possibilities answers to what if questions	The construction of the models require some special training
It diagnoses problems	The results could be difficult to interpret
It visualizes plans and prepares for changes and develops understanding	It can be time consuming and expensive
It evaluates and validates before the resources have been acquired, future changes, new designs and theories related to the elements of the system,	If used improperly it could imply significant risks
It compares alternatives It helps predicting future disturbances and test different scenarios	It frequently lacks of flexibilities needed when dealing with F/IMS and thus some assumptions should be made

Source: Modified based on [7]

Next, some modified rules for defining if simulation is inappropriate for a given case or not, [Banks, 1998 cited in 9], are listed as follows:

1. The problem can be solved using common sense analysis
2. The problem can be solved analytically
3. It is easier to change or perform direct experiments on the system
4. The cost of simulation exceeds the possible changes
5. Proper resources are not available for the project
6. There is not enough time for the model results to be useful
7. There are not data, not even estimates
8. The model cannot be verified or validated
9. Project expectations cannot be met
10. System behavior is to complex or cannot be defined.

On the other hand, from a deeper analysis on the benefits the many simulation tools offers, several authors like [7], [8], have made their comparisons and got to important conclusions which, if also taken into account that the analytical models become hard to be used due to the inner flexibility and autonomy of these kind of systems, underline in most of the cases, the vital role of such packages in the design, analysis, control and optimization of production systems, that is clearly the main objective pursued through this paper.

From such comparisons and conclusions, the Witness simulation package appeared to have a good rating, Fig. 6 shows an interface of Witness when trying to be used for the IMC described herein.

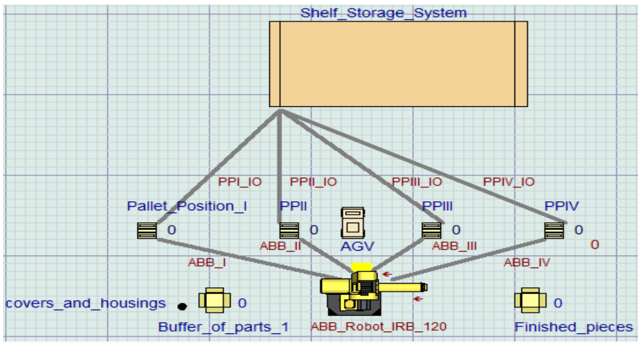

Fig. 6 Interface of Witness when partially trying to simulate the IMC

VII. CONCLUSIONS AND FURTHER RESEARCH

The present paper gave an insight into the design and analysis of the material flow both generally speaking as well as with a focus on some of the facilities of the IPSAM. At the same time a few optimization issues regarding the number of combinations for the search of the best MFC were also given. As for helping comprehending some of the descriptions and situations, both figures, a detailed layout and some expressions accompanied the sections. The paper creates a basis for a broader research project that encompasses the migration to more intelligent systems, cells or workstations. Further research ideas are related but not limited to the improvement of what was described herein and the use of simulation to explore the different scenarios. It is also an ain to apply these ideas to other systems at the institute, e.g.: a new iCIM 3000.

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REFERENCES

[1] Gausemeier, J. and Gehnen, G. (1998). Intelligent material flow by decentralized control networks. Journal of Intelligent Manufacturing. Volume 9, Number 2, 141-146, DOI: 10.1023/A: 1008815928799

[2] Kosturiak, J. &Gregor, M. (1998). FMS Simulation: Some Experience and Recommendations, Simulation Practice and Theory, Vol. 6, Issue 5, July 15, 1998, 423-442.

[3] Mudriková, A., Delgado Sobrino, D. R. and Košťál, P. (2010). Planning of material flow in flexible production systems. In: Annals of DAAAM and Proceedings of DAAAM Symposium. 20-23rd October 2010, Zadar, Croatia - ISSN 1726-9679. - Vol. 21, No 1.

[4] Velíšek, K., Šebeňová, S., Ružarovský, R. (2010). Transport systems in flexible manufacturing. In I. Central European Conference on Logistics: 26 November 2010, Miskolc, Hungary. Miskolc: University of Miskolc, 2010, s. 5. ISBN 978-963-661-946-6.

[5] Xu, D. (2001). Hardware-based Parallel Simulation of Flexible Manufacturing Systems. Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

[6] Heilala, J. (1999). Use of simulation in manufacturing and logistics systems planning. VTT Manufacturing Technology, Finland.

[7] Prasad Senniappan, A. (2001). Simulation in Flexible Manufacturing System. Department of Industrial and Management Systems Engineering. West Virginia University, Morgantown, WV-26505.

[8] Verma, R., Gupta, A. and Singh, K. (2009). A critical evaluation and comparison of four manufacturing simulation softwares. Kathmandu University Journal of Science, Engineering and Technology: vol. 5, no. i, January, 2009, pp 104- 120.

[9] Danišová, N.; Ružarovský, R. & Velíšek, K. (2012). Robotics System Design for Assembly and Disassembly Process. In WASET 67 2012

[10] Bozdana, T. (2012). Intelligent Manufacturing Systems. Introduction, definition and course outlines. Consulted on 30.09.2012. Available at: http://www1.gantep.edu.tr/~bozdana/ME534_1.pdf