A FEW ANALYSIS AND CUSTOMIZATION ISSUES OF A NEW ICIM 3000 SYSTEM: THE CASE OF THE MATERIAL FLOW, ITS COMPLEXITY AND A FEW ISSUES TO IMPROVE

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Abstract: *Due to the scope of new projects and the need of turning the existing flexible ideas into more autonomous and intelligent ones, i.e.: moving toward a more intelligent, somehow real-life oriented but at the same time educationally useful manufacturing, the present paper offers a step more into the analysis and a few customization issues of a new iCIM 3000 system at an academic-research oriented Institution. In this process, special emphasis in made on the material flow problem. For this, besides offering a description and analysis of the system and its main parts, also some tips on how to define other possible alternative material flow scenarios and a partial analysis of the combinatorial nature of the problem are offered as well; all this is done with the intentions of relating it with the use of simulation tools. For a better comprehension, the previous elements are supported by a few figures and expressions which would 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.*
Key words: *Flexible/Intelligent assembly/disassembly cell (F/IA/DC), Flexible/Intelligent Manufacturing Systems/Cell (F/IMS/C), Material Flow Analysis/Optimization/Combinations/Design (MFA/O/C/D)*

1. INTRODUCTION

The process of manufacturing migration has been taking place during the last decades; several authors have written about it and described the characteristics of each era (Chryssolouris, 2006; Papadopoulos et al., 2009; Monfared & Steiner, 1995; Rzevski, 2003 among others. One of the most relevant of those paradigm shifts has been that one (still happening) from the Computer Integrated Manufacturing and Flexible Manufacturing toward more flexible and autonomous systems. Some of these systems have remained as they originally were, while just several intelligent devices/software have been incorporated, others on the contrary, have been directly assumed obsolete and thus have been replaced.

Despite of the case, many hours of study have been required and investment in research has been needed. In all this process, automation (mechatronic) issues have been of great importance and several well-known companies have been leading the sector, e.g.: Rockwell Automation, ABB, Siemens Industry, SMC and last but not least among many others, Festo that has mainly had a key impact in the field of Pneumatics.

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 or I/FA/DC is taking place either with real life production intentions or as research projects helping to evolve the field.

Taking all this seriously, the IPSAM possesses several systems where intelligence is to be implemented and better autonomy to be reached, i.e.: (1) a FA/DC, which is composed of several subsystems, i.e. Cartesian robot (CR), Shelf-storage system (SS), a small robot (AGV) for the transportation of the parts and finished pieces inside the cell, and another one dedicated to the palletization and despalletization (ABB robot), (2) a pneumatic laboratory, see Fig. 1, and (3) second laboratory where pick and place operations and assembly-disassembly processes are carried out see Fig. 2.

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.

One of the latest and more complete systems at the IPSAM is an iCIM 3000 system acquired from Festo and its Didactic program. Having exclusive use of open standards for communication and databases as well as a modular structure of its software, this new system provides numerous possibilities for realizing a few customization ideas. iCIM 3000 comes programmed and initially constrained to certain routines and configurations, as logical, most of this basic routines and conception despite being general enough does not precisely meet all the requirements and scientific needs of an academic/research institution (IPSAM), this way this situation, also associated to the same new project's aims, demand some description, analysis and study on the possibilities of customization according to the requirement of our institute; this motivates the elaboration of the present research paper. All this is intended to be done from the logistic viewpoint. The reminders of this paper will be organized in 4 more sections which are described as follows.

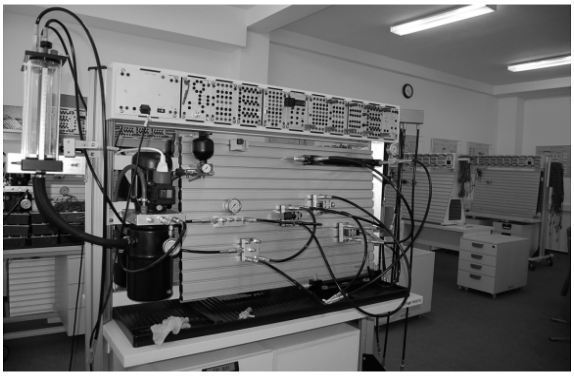

Fig.1. Pneumatic Laboratory in cooperation with Festo. Source: IPSAM archives

2. DESCRIPTION AND ANALYSIS OF THE ICIM 3000 SYSTEM

The iCIM 3000 is of the latest relevant solutions proposed by Festo Didactic for the training of students and research center's scientific needs in terms of manufacturing research. It is assumed to play an important role in illustrating complex topics such as production logistics and sequence planning in flexible manufacturing systems (FMS) while at the same time also the material supply and disposal, the planning algorithms for automated production lines among many others

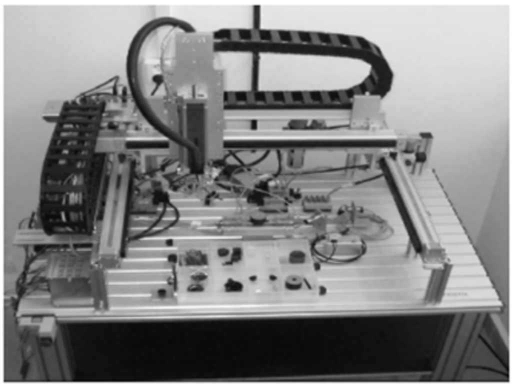

Fig.2. Cartesian robot station for the assembly-disassembly. Source: (Danišová et al. 2012)

There are a few reasons why to believe the system is a step in advance to other similar ones in terms of modularity, flexibility and open ideas, some of these are:

- Distributed intelligence based on the concept of distributed control. All stations have their own industrial controllers and can be operated stand alone on in the whole system network
- Standard interfaces and communication. Most of the industrial level components and subsystems line CNC, robots, vision systems, PLC, etc. are compatible
- World class CELL/LINE control concept. It uses the most powerful factory integration software available in the market, i.e.: Cosimir Control. This includes all SCADA features and more. A high level process plan language makes it easy to define several processes at a time in a real multitasking operating system. The powerful set of communication drivers include makes it also easy to integrate to most of the automation equipment brands.

Related to this, iCIM 3000 gives the user the chance to use either isolated modules of it or all of them at a time, being possible to incorporate modules as it may be needed. Figure 3 gives an insight to what has been said and the system's general framework itself.

The system consists of two CNC processing centers respectively 1) CONCEPT TURN 105 and 2) CONCEPT MILL 105, it also it includes 3) a Flexible Robot Assembly Cell (FAC), 4) and 5) two flexible robot feeders that carry out CNC-related loading/unloading operations, 6) a quality station QH 200 with a pallet handling device where baseplates will be checked for the diameter of the holes milled, 7) a pallet conveyor system, 8) an Automatic Storage / Retrieval System (AS/RS). Fig. 4 shows a 3D layout configuration of the specific system. Notice that 1) and 4) or 2) and 5), together can be referred to as small individual FMCs or even as a small FMS if assuming all of them to be a single unit.

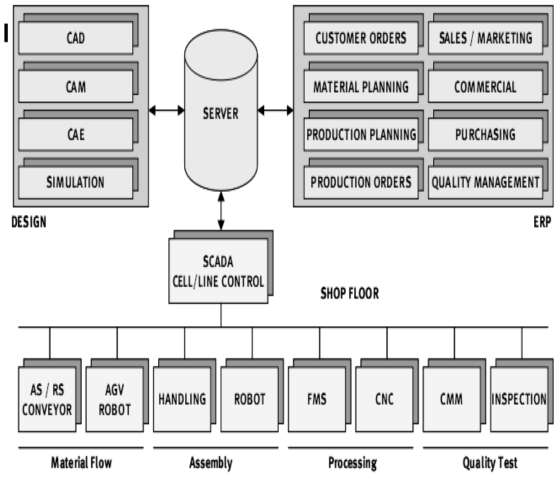

Fig.3. General framework for the iCIM 3000 functioning. Source: (Festo Spol. SR., 2012)

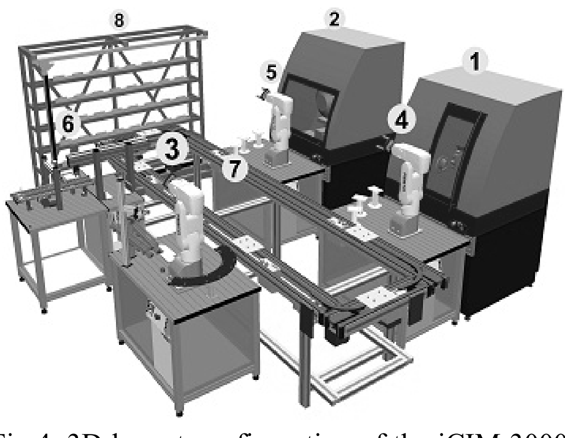

Fig.4. 3D layout configuration of the iCIM 3000 at the IPSAM. Source: Self-elaboration.

In general terms, the pallet conveyor system is the center of the iCIM 3000 system. It has the task to transfer the pallets with workpieces from the AS/RS to the different stations and vice versa. For this, a number of 8 carriers move with the conveyor, ready to take over a pallet to bring it to the target. The carriers are coded with memory chips, which are read out at the carrier stop gates. Stop gates are placed at all positions, i.e.: at stations like the FMCs, FAC, AS/RS and the quality inspection.

The codes of all carriers in a system are different. When a carrier reaches a stop gate, the carrier's code is read out by the Conveyor Controller (PLC) and is send to the CELL/LINE Controller for online tracking and visualization. On the other hand, the CELL/LINE Controller sends the next command to the iCIM according to the process plans.

The Stop Gates have a pneumatic stopper cylinder, an inductive sensor for pallet detection and an identification sensor with decoder to read out the carrier codes. These signals are transferred to the conveyor PLC by means of an industrial Fieldbus, e.g. PROFIBUS.

The AS/RS is the main storage for all material used in the iCIM production, raw and semi-finished parts as well as end products. All workpieces are stored on standard pallets, equipped with fixtures for each specific workpiece. Forty of these standard pallets can be stored in 5 rows with each 8 shelves in the rack. An industrial type, Cartesian 3 axis servo robot, controlled by a PLC or IPC, moves the pallets from the shelves to the carriers on the conveyor system and vice versa.

The location of the workpieces is stored in an AS/RS –Manager – Database. When a process requires a specific part out of the AS/RS, a request is send to the AS/RS – Manager. Based on the Database, the location of the specific part is found. Then the AS/RS – Manager sends a command to the AS/RS – Robot – Controller to restore the part out of the specific shelf. The storage can be divided in several zones, i.e.: different types of material can be stored in special shelves, e.g.: for example, finished parts should be stored always in shelves 30 and 40. This feature is useful to keep a clear structure in the AS/RS and constitutes an important constraint in the analysis of the system.

The robot of the FAC is designed for the assembly of a desk set. The cell can, however, be restructured for handling other similar workpieces within the kinematic range of the robot. The robot cells are ideal both for integrated application as part of a production system and for use as an individual station. This also applies to other stations like CNCs.

In iCIM (networked) operation, all the available single robot programs are triggered by the CELL/LINE Controller via the iCIM task tool and handshake procedure on Ethernet TCP/IP to perform a complete assembly job. Both, program name and parameters are sent to the robot controller. Creation of new robot tasks is relatively easy, i.e.: write a new program in the multitasking environment of the robot, e.g. TEST77, define the parameters, teach the

positions and basically that's all. However, by means of the CELL/LINE Controller, the task TEST77 can be started in a single task operation or can be integrated into a process.
All FMCs and FAC in iCIM can be equipped with local raw material feeders, e.g..: 4) and 5) and local buffers. Materials flow to and from the stations takes place by means of conveyor system, however an AGV could be also used if necessary what proves the flexibility and certain autonomy of each of the stations.
For FMSs the communication method is very similar to the above described for FAC. But, an additional communication channel is established from CELL/LINE Controller to the CNC Controllers. This is to select the CNC program number in real-time according to the production planning.
A family of desk sets is the ideal product to show everything in a factory and that is why the iCIM 3000 system comes with it pre-programmed. The parts list, see Fig. 5, contains purchased parts as well as parts to be produced in the same iCIM. The most important production steps like CNC processing, quality control, assembly, buffering, storing and delivery can be shown for these parts. Many different variations of the product can be produced by variation of the materials and assembly positions. Thus, the complexity of a today's production down to lot sizes of 1 is the object when utilizing iCIM.
The product can also be produced in different variations depending on the customer's order. Materials and shape of the base plate and the penholder can be changed to form a customized product, and the position of the hygrometer and thermometer can be selected.
Another possibility to create different desk sets is to assemble, for example, only one or none instrument or no pen. Thus, the variations are several hundred and enough to make experiments related to logistics, flexible assembly and manufacturing, Fig. 6 shows the desk set to be initially produced. A few more issues of the complexity of the problem and number of combinations is further explained herein

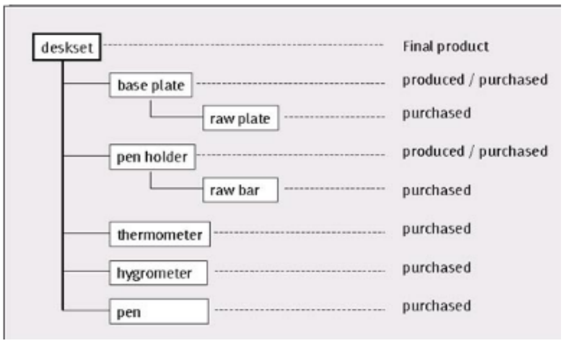

Fig.5. Parts list structure. Source: (Festo Spol. SR., 2012)

Fig.6. Desk set to be initially produced. Source: (Festo Spol. SR., 2012)

In the pallet handling and quality station, pallets loaded with work pieces are picked up from the conveyor belt by the electro pneumatic XZ-handling device and are placed at the transport belt, which moves them under the measuring tool. Driven by a pneumatic linear actuator, the probe moves down and detects the diameter of holes in the work pieces. This is a very typical industrial application in various production plants and thus useful at our institute both for the teaching and research processes. After the measuring process, the pallets with tested products are put back to the conveyor system. Parts which have failed the test are moved to the stations output position.

3. ANALYSIS OF THE MATERIAL FLOW AND ITS COMPLEXITY

As already mentioned before, the iCIM 3000 system offers the chance of diversity in terms of the range of items to produce. This way complex analysis, not necessarily included in the initial philosophy, could be carried out. Some of those many analysis are the combinatorial nature and complexity of the problem itself. Authors like Delgado Sobrino et al. (2012) and Delgado Sobrino & Velíšek (2013) have addressed this issue from the MFA and optimization viewpoint. They have taken into account the number of combinations among the many varying elements/devices of a system while

Chryssolouris (2006) and others have also at least partially addressed these issues.
In the specific iCIM 3000 located at the IPSAM, see Fig. 4 again, the analysis of the MF is also a complex and combinatorial problem. Most of the optimization complexity of it lies on the AS/RS and its conjugation with the many other devices included in a MFC analysis. Some of the variables to take into account so as to know an approximate number of combinations among such devices are: working speeds of the devices and associated time standards, priorities (general priority rules or other specific case study-oriented ones), working modes, etc. These variables, if also taking into consideration the number of different items to produce and a certain number of initial/general possible working scenarios, let's also call them as scheduling alternatives, could give us an idea on how to determine such a number of MFC in terms of the iCIM 3000 system´s mentioned varying elements. The number of combinations can be determined through the following expression 1:

$$TNC = \left\{\sum_{t=1}^{v}\left[\left(\prod_{d=1}^{e} NV_{d,t}\right)\left(\sum_{s=1}^{\alpha} ISc_s\right)(P_Z)\right]\right\} \quad (1)$$

where:
NVd, t: total number of values that the element d of system (device) has in its discreet or discretized varying scale for a certain part, product or family t; $d = \overline{1,e}$ and $t = \overline{1,v}$
Pz: Number of prioritizations, $z = \overline{1,p}$
NPt: Number of parts, products or families having different technological specifications; if a part, product or family t does not need to be processed at a given device d, then NVd, t = 1 so as to avoid the equation nullity.
IScs: general scenario or initial scenarios clearly visible and identified by the researcher without any combination expression, let us also call them scheduling alternatives and $s = \overline{1,\alpha}$.
Notice that if the number of combinations determined is large, i.e.: TNC > TNCl, and there is a need of selecting the best product variants to produce, then it will be necessary to apply a construction method for the MFD, e.g.: heuristic, which guarantees a proper (nearly optimum) initial solution on which to start a local search analysis and thus try to possibly avoid being stuck in a local optima. On the contrary, if the number is relatively small, i.e.: TNC ≤ TNCl, then this procedure could instead directly continue with the application of multiple criteria methods (domination and satisfaction criteria), the simulation of the remaining alternatives, the analysis of the simulation results, the search of alternative solutions, the analysis of the quality of the solutions and finally with the representation of the best MF configuration via a flow diagram/travel charts
Also notice that, given the conditions of a certain use case, TNCl stands for a part or limit of the total number combinations to be defined as the maximum suitable number of combinations that could be completely listed, simulated, analyzed, etc., in a prudential time, in an exact fashion. More information about this can be all found in Delgado Sobrino et al. (2012) and Delgado Sobrino & Velíšek (2013).

4. A FEW ISSUES TO BE IMPROVED AND/OR CUSTOMIZED AND THEIR RESPECTIVE COURSES OF ACTION

Despite being the system new and theoretically in optical conditions, there have been identified a few problems that are subject to be improved and worthy of a deep analysis:

1. The LED placed in the FAC should be stabilized or even changed. Simple changes in the environment illumination affect the right positioning of the objects **(Thermometer and hygrometer)** in the base plate, thus the camera software should be sometimes manually adjusted. For this, natural illumination stabilized, e.g.: a. the camera should be isolated using some kind of housing, b. the windows should be painted with dark color and better curtains should be added, others
2. The iCIM 3000 should be programmed so that the parts of a given production order are not unnecessarily stored when they will have to be retrieved right away their storage. This is unnecessary and still happening with some of production orders, e.g.: Once the baseplates have been checked and passed the quality control, they should be directly sent to the FAC instead of keep circling till they are stored at the AS/RS and retrieved right away to be then sent to such FAC.
3. Different designs and shapes are to be created by using the same CAD/CAM software of the iCIM 3000 or other software like Catia V5, AUTOCAD, etc., the higher the diversity and difference of the new pieces, the higher the complexity and tools, software, etc. adjustments to be done. This

will also increase the number of products combinations. At present some of the original parts have been already modified, the changes made so far have still allowed us to keep using the same system's default configurations. Fig. 7 and Fig. 9 respectively show both a penholder and baseplate modified from their default shapes. This is a challenge for the research team to face and overcome.

4. When producing a complete set, the fixed order of operations should be revised, i.e.: the most time consuming operation should be started first even when being the last in the conveyor system (milling operation). It balances the system and improves its utilization.

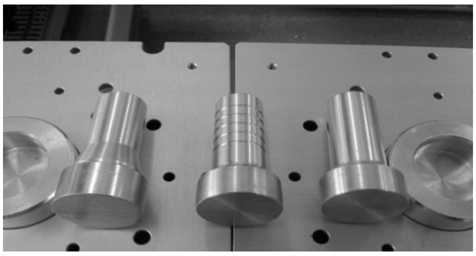

Fig.7. Default penholder shapes and new manufactured penholder after having modified its shape using the CAD/CAM software of iCIM 3000 (the first one on the left). Source: IPSAM archives.

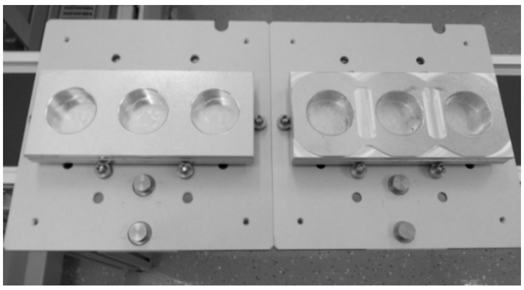

Fig.8. Default baseplate shape (on the left) and manufactured penholder after having modified its default shape using the CAD/CAM software of iCIM 3000. Source: IPSAM archives.

5. CONCLUSIONS AND FURTHER RESEARCH ISSUES

This paper dealt with the description and analysis of an iCIM 3000 system existing at the IPSAM. A few problems, customization issues as well as the complexity of the MF were addressed as well. An insight into the analysis and calculation of a number of MFC was also given and it was related to the selection of appropriate solutions methods. Further research ideas lie on implementing solutions to the few problems identified and also are aimed at start working on other MF- related decisions like the layout analysis, buffer capacity, lot sizes, possibilities of scheduling, etc.

6. ACKNOWLEDGMENT

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