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On the Analysis and a Few Optimization Issues of a New iCIM 3000System at an Academic-Research Oriented Institution

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***Abstract*—**In the past years, the world has witnessed significant work in the field of Manufacturing. Special efforts have been made in the implementation of new technologies, management and control systems, among many others which have all evolved the field. Closely following all this, 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 manufacturing, the present paper emerges with the main aim of contributing to the analysis and a few customization issues of a new iCIM 3000 system at the IPSAM. 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 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 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.

***Keywords*—**Flexible/Intelligent assembly/disassembly cell (F/IA/DC), Flexible/Intelligent Manufacturing Systems/Cell (F/IMS/C), Material Flow Optimization/Combinations/Design (MFO/C/D).

I. Introduction

IN today´s complex and dynamic markets it has become increasingly necessary for manufacturers and academic-research oriented institutions, to start working and using new manufacturing trends and technologies. This process of migration has been taking place during the last decades; several authors have written about it and described the characteristics of each era [2], [11]. One of the most important 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 several intelligent devices/software have been incorporated, others, on the contrary have been directly assumed obsolete and thus have been replaced.

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In each one of the cases hours of study have been required and investment in research has been needed. In all these process, automation (mechatronic) issues have been of great importance and several well-known companies have been leading the sector, e.g.: Festo.

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

Conscious of this, the IPSAM consists of several systems where intelligence is to be implemented and better autonomy to be reached, i.e.: (1) a FA/DC, see Fig. 1, 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. 2, and (3) second laboratory where pick and place operations and assembly-disassembly processes are carried out see Fig. 3.

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, toward a more

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intelligent, evolved and autonomous conception.

One of the latest and more complete systems at the IPSAM is an iCIM3000 system provided by 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 present paper elaboration. All this is intended to be done from the logistic view point. The reminders of this paper will be organized in 4 more sections which are described as follows.

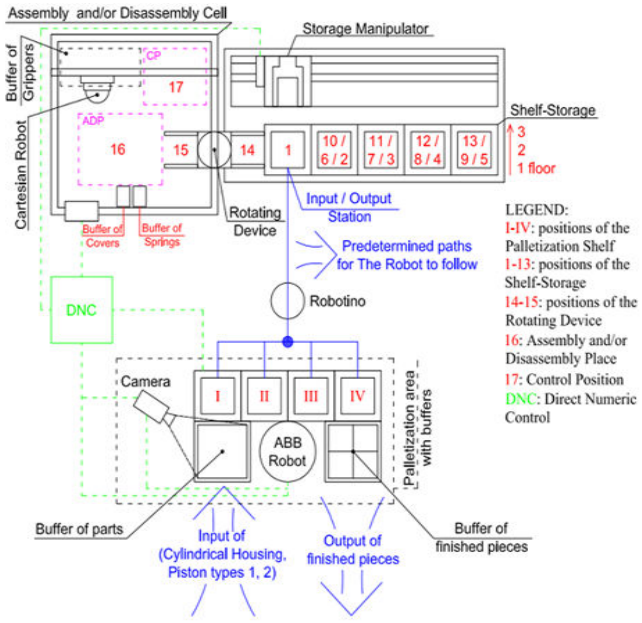


Fig. 1 Detailed Layout intended for the IMC Source: Self-elaboration



Fig. 2 Pneumatic Laboratory in cooperation with Festo. Source: online MTF STU archives

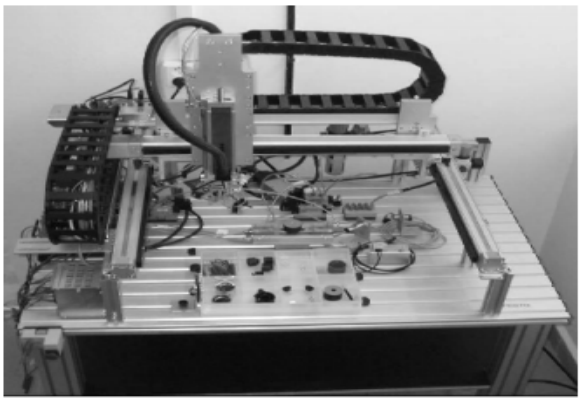


Fig. 3 Cartesian robot station for the assembly-disassembly [3]

II. Description and Analysis of the iCIM 3000 System

The iCIM 3000 is of the latest elevant 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):

- Material supply and disposal
- Planning algorithms for automated production lines
- Many others.

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. Fig. 4 gives an insight to what's 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), 5) two flexible robot feeders that carry out CNC-related loading/unloading operations, 6) a pallet handling and quality station where items will be checked, 7) apalletconveyor system, 8) an Automatic Storage / Retrieval System (AS/RS). Fig. 5 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 FMC themselves. The previous devices are briefly described as follows:

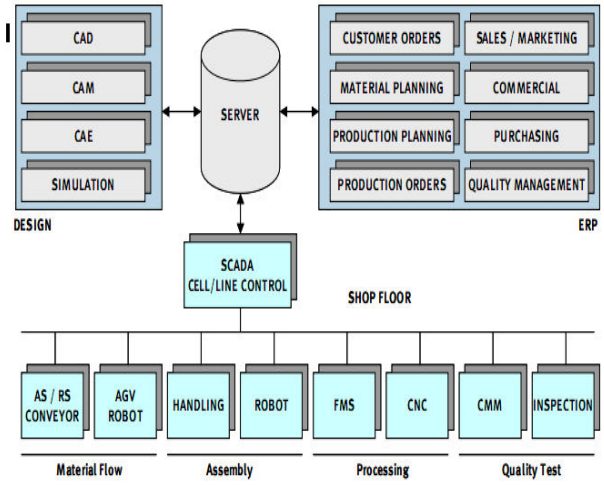


Fig. 4 General framework for the iCIM 3000 functioning [7]

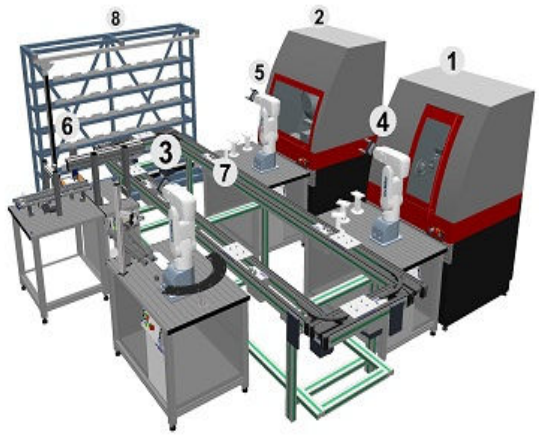


Fig. 5 3D layout configuration of the iCIM 3000 at the IPSAM
Source: Self-elaboration

Generally, the pallet conveyor system is the center of the iCIMsystem. 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 carriers circle on the conveyor, ready to take over a pallet to bring it to the target. The carriers are coded by means of memory chips, which are read out at the carrier stop gates. Stop gates are placed at the AS/RS position as well as at all positions, where iCIM stations like FMS, Assembly Robots or Inspection Systems are placed.

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 FAC offer deals with all aspects of robotized assembly and handling processes. Initially, the robot cell is designed for the assembly of a desk set. The cell can, however, be restructured for handling other 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.

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, you can start the task TEST77 in single task operation or you can integrate this new task in a process.

All FMSs in iCIM can be equipped with local raw material feeders, i.e.: 4) and 5), as well as local pallet buffers. Material flow to and from the FMS take place by means of conveyor system; however, an AGV could be also used if necessary.

For FMSs the communication method is very similar to the above described 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 desksets 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. 6, contains purchased parts as well as parts to be produced in the factory. The most important production steps like CNC processing,

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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 desksets 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 the part list structure of the deskset to be produced while Fig. 7 shows the deskset itself. A few more issues of the complexity of the problem and number of combination will be further explained in this paper.

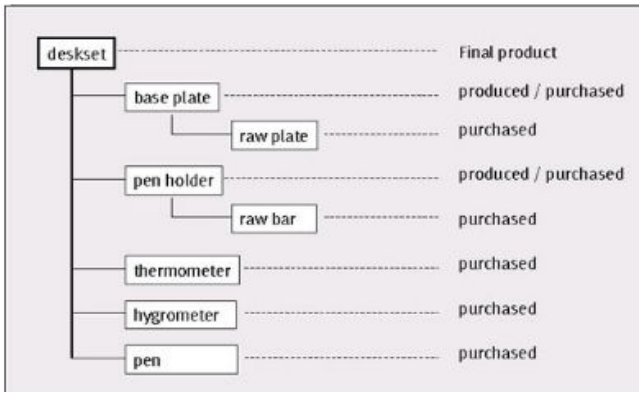


Fig. 6 Parts list structure [7]



Fig. 7 Deskset to be initially produced [7]

In the pallet handling and quality station, pallets loaded with workpieces are picked up from the conveyor belt by the electropneumatic 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 workpieces. This is a very typical industrial application in various production plants. 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.

III. A Few Customization Issues and Analysis to Be Done

As it has been mentioned before, the iCIM 3000 system offers the chance of diversity in terms of the range of items to produce. In such contexts, complex analysis, not necessary included in the initial philosophy, could be taken into account. Some of those many analysis are the combinatorial nature and complexity of the problem itself. Authors like [4], [5] have addressed such issue from the Material flow viewpoint, in the search of its analysis and optimization taking into account the number of combinations among the many varying elements/devices of a MS, [2] and others have also at least partially addressed this issue.

In the specific iCIM located at the IPSAM, see Fig. 5 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 (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:

$$TNC = \{\sum_{t=1}^{v}[(\prod_{d=1}^{e} NV_{d,t})(\sum_{s=1}^{\alpha} ISc_s)(P_z)]\} \qquad (1)$$

where:

NVd, t: total number of values that the element d of cell (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 $s = \overline{1, \alpha}$

Notice that if the number of combinations determined is large, i.e.: TNC >TNCl, 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

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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), see [10], the simulation of the remaining alternatives [1], 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 [4]-[6].

IV. Using Other Simulation Packages for ICIM Optimization

Commonly, 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 and IMS as a set of interconnected queues, in which a workstation 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 unlike other production systems, 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 similarly occur 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 works 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 cannot 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. 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:

TABLE I
Main Advantages and Disadvantages of the 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 frequently lacks of flexibilities
It helps predicting future disturbances and test different scenarios	needed when dealing with F/IMS and thus some assumptions should be made

Source: Modified based on [8]

Considering what is stated in the previous table and also taking into account Banks (1998) cited in [12], some rules commonly found in the literature for defining if simulation is inappropriate for a given case or not 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 each one of the many simulation tools offers, several authors like [8], [9], 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.

Such comparisons and conclusions, along with the points addressed before, made possible for the authors of this paper to verify the superiority of the Witness simulation package.

V. Conclusions and Further Research Issues

This paper dealt with the description and analysis of an iCIM 3000 system existing at the IPSAM. Together with this a few customization issues as well as the complexity of the problem were addressed mainly from the material flow viewpoint. An insight into the analysis and calculation of a number of MFC was also given, while relating it with the selection of appropriate solutions methods as a function of such a number of MFC. At the end, the importance of using simulation was highlighted as well as the relevance of the Witness simulation package. Further research ideas lie on moving to the steps of

layout analysis and other MF- related decisions like buffer capacity, lot sizes, possibilities of scheduling, etc., so that, to finally go for the needed data acquisition and start applying heuristic methods and/or directly simulating.

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