

A PROCEDURE FOR INTEGRATING AUTOMATED EQUIPMENT IN A FLEXIBLE MANUFACTURING SYSTEM AND THEIR USE FOR THE REMOTE MANUFACTURE OF PARTS THROUGH THE INTERNET

João Carlos Espíndola Ferreira

Universidade Federal de Santa Catarina, Departamento de Engenharia Mecânica, GRIMA/GRUCON, Caixa Postal 476, CEP 88040-900, Florianópolis, SC, jcf@grucon.ufsc.br

Marcelo Teixeira dos Santos, Leo Schirmer, Bruno Francisco Cardoso, Hugo Gaspar Santos

Sociedade Educacional de Santa Catarina, Instituto Superior Tupy, Rua Albano Schmidt, 3333, CEP 89201-972, Joinville, SC, teixeira@sociesc.com.br

Alberto José Álvares

Universidade de Brasília, Departamento de Engenharia Mecânica e Mecatrônica, Grupo de Automação e Controle (GRACO), CEP 70910-900, Brasília, DF, alvares@AlvaresTech.com

Abstract. A procedure for integrating pieces of equipment in a FMS is presented in this paper, which involves the physical connection of that equipment, and the development of the FMS control software. In the control software it is applied a two-level hierarchical approach: station and equipment. It is proposed the use of finite automata to support the generation of the control software on the two levels. On the station level, it is proposed the development of a decision-making module about the orders to be manufactured in the FMS, and among these decisions it is included the determination of the production sequence of the parts, and the NC code generation for manufacturing each part. Once the control software is implemented, it is intended to make it available on the Internet, so that people who can be located anywhere in the world access it. Basically, the client will enter the FMS site through the browser, and he/she will input an order containing data about the part and the batch size. That order will be included in the list of orders for the FMS, and later it will compete for the FMS resources. Besides, means to obtain information about the order will be made available for the client. After manufacturing the batch, it can be sent to the client. This procedure is being implemented at SOCIESC (Joinville, SC), which has a robot, an automated storage and retrieval system (AS/RS), a CNC lathe and a CNC milling machine.

Keywords. Flexible Manufacturing System, Remote Manufacturing, Control Software, Computer-Aided Manufacturing, Internet.

1. Introduction

For many years the manufacturing companies all over the world have been immersed in a quite competitive atmosphere, in which products of equal or better quality, with good prices, have been competing for conquering a market niche. At the same time, this competition caused by the globalization has been leading companies to look for cooperation with other companies so that they remain competitive.

A factor that has been accelerating globalization is the Internet, which has been changing the people's life all over the world, and one of its main characteristics is the elimination of the distances for information exchange. Some activities that have been made through the Internet are:

- search of information in general (Google, 2003);
- teaching (Cyberlearning, 2003);
- purchase and sale of products (Saturn 2003);
- telesurgery made by a robot commanded remotely by a surgeon located hundreds of kilometers away (Scientific American, 2000).

Besides the greater availability of information for the customers, and also the customer's significant approximation to the company, the prices of products sold through electronic trade are usually lower, due to the elimination of expenses with rental of commercial points, and with the amount of employees.

The Internet has already been giving a great contribution to manufacturing, since it allows the communication among different departments of a company seeking the exchange of information such as:

- operations to be made in a product;
- information on the material requirements at a certain station;
- possible feedback for the Engineering Department about modifications in product design that will be necessary for reducing its production costs. And these departments may be located in different cities and even countries. Besides, it is possible that one or more suppliers are connected to this chain through Internet.

Besides this corporate applicability of the Internet, it can be considered its use for remote programming and monitoring of manufacturing equipment. For instance, a program for robot simulation can be executed through the Internet in order to learn the kinematics and dynamics of the robot (Robosim, 1999). Also, information can be sent to a real robot at a very distant location, so that it performs certain activities (Telerobot, 1998). Another important manufacturing application is the availability of a CAD/CAM software to be used by a remote user (Cybercut, 2000).

Once the Internet allows the virtual approximation among people/companies located geographically distant amongst themselves, it can also be used as a technology to allow remote manufacture of parts. This way of producing parts is motivated by the fact that the customer does not necessarily possess the pieces of equipment and accessories for producing the parts. From the point of view of the company that executes the manufacture, it gets in touch directly with the customer, when answering quickly to the request concerning the quality of the product and time of delivery, and in this manner it may not only maintain its market niche, but also increase it.

Another important characteristic of a manufacture company is the capacity to manufacture different parts with small or medium batch sizes, in order to supply high quality products. According to Lorini (1993), 75% of the products in the USA were (and still are) produced in batches of 50 or less units. A type of manufacture system that satisfies this demand is the Flexible Manufacturing Cells - FMCs. Therefore, companies having this level of demand need to acquire and install FMCs or Flexible Systems of Manufacture (FMSs).

A Flexible Manufacturing System (FMS) it is composed typically by CNC machines, automated storage and retrieval systems (AS/RS), and one or more robots, all physically interconnected, and the control of the whole system being made by a software. Caterpillar and John Deere are among the companies that have been implementing FMSs in their facilities.

FMSs can be acquired directly from some suppliers, however in that case the control software comes with FMS, and if the user of FMS wants to update the system (p.ex. with the purchase of a new equipment), the supplier will have to be contacted to update the software, and such activity, besides being costly, can be slow. This is probably the largest source of inflexibility of FMSs, which contributes negatively to their proliferation in manufacture companies.

Once the control software is implemented, it is intended to make it available in the Internet, so that it is accessed by people who can be located anywhere in the world (figure 1). Basically, the customer in a place *x*, through the browser in his/her microcomputer, enters the FMS site (located in place *y*), and he inputs an order with the following information: part data and batch size. That order is added to the list of FMS orders, and later it will be competing for the FMS resources. Finally, after producing the batch, it can be sent through normal mail for the customer.

The software for the design and production of the parts is located at the Federal University of Santa Catarina (UFSC), in Florianópolis, SC, while the manufacturing equipment is located in the Education Society of Santa Catarina (SOCIESC), in Joinville, SC. The pieces of equipment are: an articulated robot, an automated storage and retrieval system (AS/RS), a CNC lathe and a CNC mill.

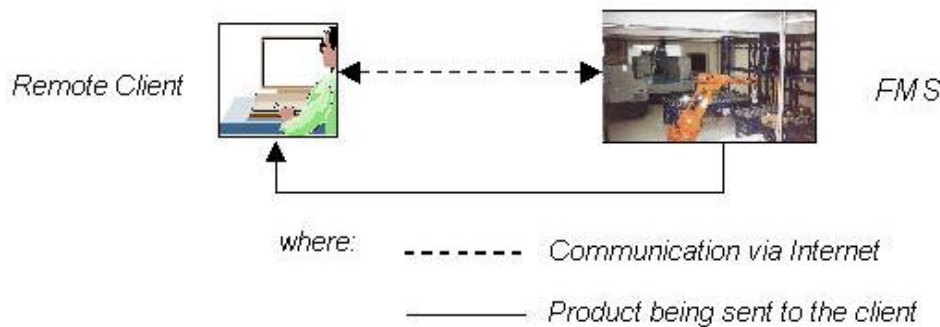


Figure 1. Illustration of the applied approach for the remote manufacture of parts in a FMS

2. Description of the Activities

2.1. Development of the FMS Control Software

A FMS should present the productivity of a dedicated line, and at the same time it should be capable of manufacturing different parts as a job shop. In fact, although FMSs possess these characteristics, the company becomes dependent of the supplier with regard to control software updates, which are frequently necessary due to the dynamics of the productive system. This in essence turns FMSs inflexible, inhibiting their implementation in a large portion of manufacturing companies.

Among the sources of inflexibility of the FMS control software, there are: (i) strong coupling of the functions executed by the software; (ii) rigid code of the control logic; (iii) routing and sequencing information of the part is embedded in the control software. Therefore, it is important that the control software can be updated by the company workers themselves, resulting in an effective flexibility of the FMS, in the case of physical changes in the system and demands of production. It is important that this methodology of updating of the control software results in the reduction of time, effort and development cost of the software.

The method being presented in this paper seeks not only to facilitate the alteration of the FMS control software, but it can also be used to turn FMS operational (i.e. totally automated, controlled by computer) soon after the arrival of the equipment (Smith et al, 1996).

The control architecture of the facility should provide a procedure for the design and development of the control software. Dilts et al. (1991) identified some control architectures of automated manufacturing systems, among which are included:

- centralized control, in which a single controller performs the control of the whole shop-floor;
- hierarchical control, which decomposes the control problem in specific levels, and each level is designed with a certain autonomy in relation to the other levels.
- heterarchical control, where distributed autonomous entities communicate with one another, without the client/server relationship of a hierarchical architecture.

In figure 2, the hierarchical approach is illustrated, in which the equipment level can include physical devices as CNC machine tools, industrial robots and automated storage and retrieval systems. The equipment controller makes decisions on the sequence of operations, adjustment of machining parameters, and it monitors the operations to verify possible mistakes. The station level is defined by the equipment layout, and it consists of two or more pieces of equipment. A FMS can be composed of one or more stations, and the station controller is responsible for sequencing the parts through the machines, and for synchronizing the necessary actions to coordinate the processing, handling and storage equipment during the movement of the parts.

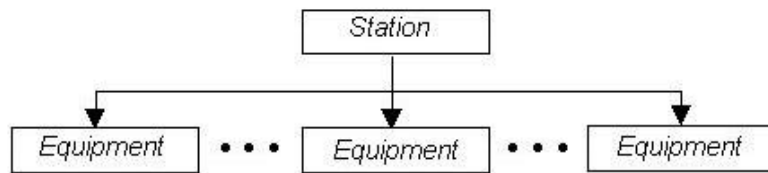


Figure 2. Hierarchical structure of the FMS controller

Each controller, in each level of the hierarchy, performs the planning, scheduling and execution activities (figure 3). The planning function determines what the controller should do to satisfy the demands, while the scheduling function determines a "good" sequence of planned tasks. The execution function executes the individual tasks.

For the implementation of the software for interfacing the equipment, it is applied the MPSG approach ("Message-based Part State Graph") (Smith and Joshi, 1993). MPSG is a finite automata that represents activities to be executed by the equipment, which are represented by arrows, while the nodes represent equipment states. These activities include the execution itself, the receipt of the order to execute the activity, and the information about the conclusion of the activity to be sent to the "upper executor".

MPSG aims at generalizing the activities executed by each equipment class. For instance, the **MH** class corresponds to a "material handler", and an instance of this class is a robot. A MPSG exists for the **MH** class, and the possible activities performed by a robot correspond exactly to those included in that MPSG. The same is applied to the **MP** class (material processor), and an instance of this class corresponds to a CNC machine. A MPSG for a material processor is shown in figure 4.

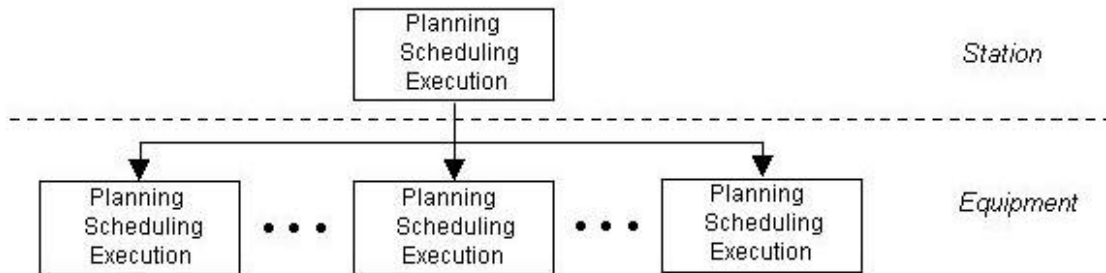
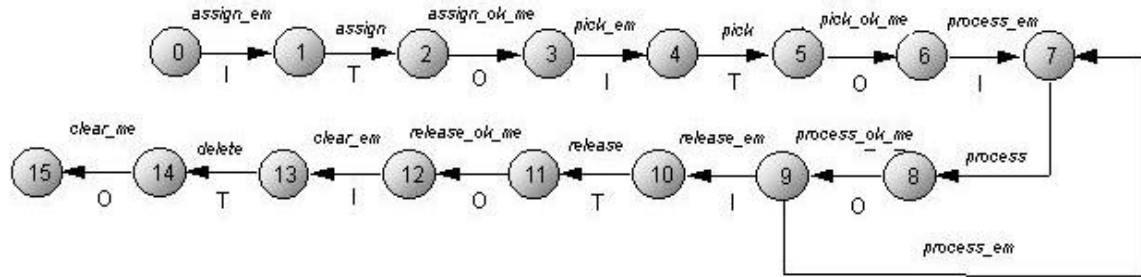


Figure 3. Hierarchical structure of the FMS controller including the planning, scheduling and execution functions



Where:

"I" = input; "T" = task; "O" = output

"e" = upper executor; "m" = machine; "em" = upper executor @machine;

"me" = machine @upper executor

Figure 4. MPSG for the **MP** class (material processor)

Besides the **MP** and **MH** classes, the **BS** class will be considered ("buffer storage"), and an instance of this class is the automated storage and retrieval system. The MPSG is represented by a text file that is read by a program (that can be written in languages such as C++), which generates source files also in C++. These source files can be modified a way to be quickly adapted to the specific conditions of the cell. After the modifications are made, these files can be compiled, and the resulting program is used to control the specific equipment (Smith and Joshi, 1993).

The basic reason for the use of MPSG is the speed that it provides for modifying the control logic of a given piece of equipment. By using this approach, the insertion of new equipment in the cell takes a significantly shorter time.

2.2. Pages for the Internet

The pages for the Internet to receive the customer's information for producing the part batches are shown in figure 5. This information includes the geometry type of the part and the batch size (figure 5a). Based on this information, the software verifies whether the ordered part was manufactured previously in the FMS. If it has been manufactured, its process plan is extracted immediately from the database, and the order is directed to the queue of production orders. If the part is a new one, the customer inputs the part through the feature-based CAD module (figure 5b), and the module then displays the data of the introduced feature (figure 5c). This program can be executed in the link <http://einstein.grucon.ufsc.br/peca/tipopeca.jsp>. After concluding the input of the whole part, the CAPP module is called for generating the processes plan (Ferreira and Andriolli, 2001).

Another CAD module was developed for the creation of solids representing stepped shafts via Internet using the ACIS kernel (Spatial Technology, 2003). In this software, the user inputs in his/her browser the information on the shaft that he/she wants to create, and these data are sent to the server, which executes the function in C++ for creating the solid in ACIS through CGI (Common Gateway Interface). In order for the user to visualize the shaft in his/her browser, the format of the solid in ACIS is transformed into the VRML format (Virtual Reality Markup Language), and soon afterwards it is sent to the user's browser. The stepped shaft may contain cones and chamfers besides cylinders (figure 6). This program can be executed in the link <http://einstein.grucon.ufsc.br/acis1>.

2.3. Development of the process planning and manufacturing modules (CAPP/CAM)

For producing the parts, decisions should be made on which machining operations will be necessary to attain the desired form and quality of the part. This activity corresponds to process planning, and in this work the process plan contains alternative operations, since a certain surface can be obtained in different ways. The process plan is represented through a matrix called Halevi Matrix (Halevi, 1999).

In this approach, the Universal Halevi Matrix is generated, which does not consider the machines initially present in the manufacturing system. Later, the Halevi Matrix is obtained considering the machines in the FMS (see an example in figure 7). Then the matrix is linearized, aiming at determining the routing (that is, the sequence of machines that will be used) for producing the part. The method of Halevi can be performed for different parts in the following link: <http://einstein.lmp.ufsc.br:8080/jsp/nosso/halevi/index.jsp>.

Nome da peça:

Tipo de Geometria da Peça:

Tamanho do lote:

(a)

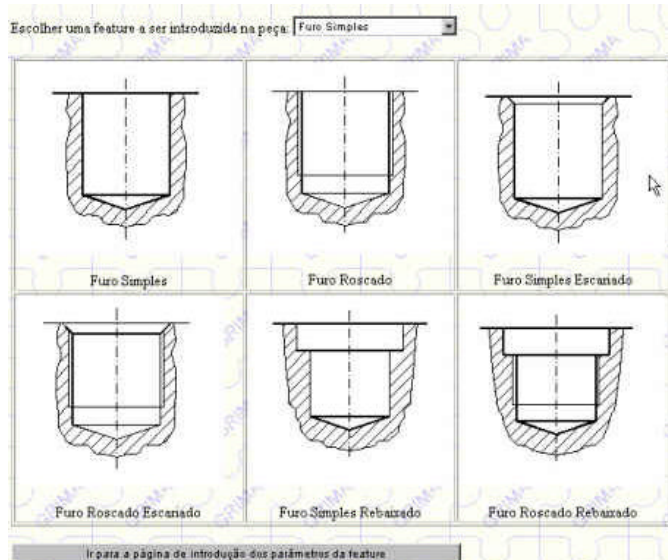
```

Diâmetro (mm) = 10.0
Tolerância no diâmetro (mm) = 0.2
Direção X = 0.0
Direção Y = 0.0
Direção Z = -1.0
Passante? true
Profundidade (mm) = 10.0
Rugosidade (micrometros) = 5.0
Tolerância de Posição (mm) = 0.1
Cota X (mm) = 10.0
Cota Y (mm) = 10.0
Cota Z (mm) = 20.0
Superfície de referência (cota X) a partir da origem?
Superfície de referência (cota Y) a partir da origem?
Superfície de referência (cota Z) a partir da origem?

```

[Outra feature](#)

(c)



(b)

Figure 5. (a) Part input; (b) Feature input; (c) Verification of the feature parameters

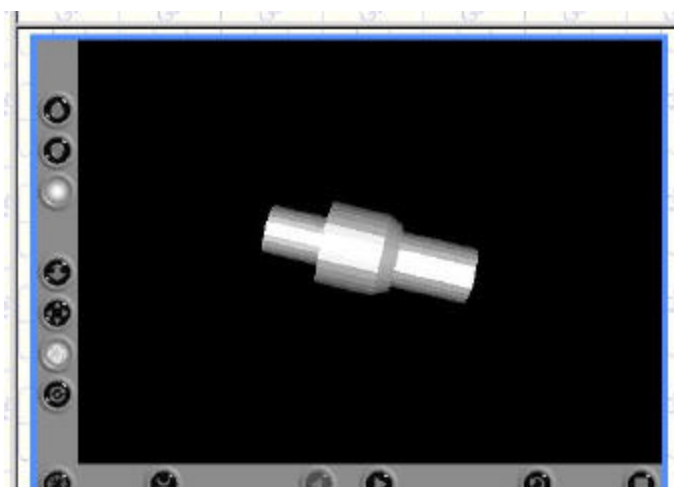


Figure 6. Stepped shaft created via Internet using the ACIS kernel and the CGI and VRML technologies.

For machining the part, the NC program (code "G") should be generated. That is done by traversing each line of the linearized Halevi Matrix, and when identifying the operation corresponding to the specific line, a group of NC blocks is determined, and the values of the attributes are instanced. A group of numerical control blocks for twist drilling at a CNC machining center is illustrated in figure 8 (Ferreira et al, 2001), and in this same illustration a portion of a NC program is shown, generated for a hole. The complete NC program is obtained combining the portions of blocks for all of the surfaces present in the part.

Operação		Máquina	Custo	Tempo
Nova	Antiga			
1	1	5	1,62	1,62
2	2-5	2	2,13	0,71
3	3-7-8-9	6	3,32	1,76
4	4-6	3	10,318	7,37
Total			17,588	11,46
4 penalties			4 x 0.2	4 x 0.03
Total			18,388	11,58

Figure 7. Halevi Matrix for producing a certain part in a group of machines in a manufacture system (Ferreira and Andrioli, 2002)

```
G00 X <x> Y <y> H0 M6 T <cutting tool>
H <tool offset> Z <z + 0.10>
Z <z + 0.10>
G01 Z <z - depth> S <rpm> F <feed> M3 M8
G00 Z <z + 0.10>
Z <z + 0.10> M5
```

```
G00 X10 Y10 H0 M6 T6
H2 Z21.0
G01 Z8.0 S2,387 F0.1 M3 M8
G00 Z21.0
Z21.0 M5
```

Figure 8. Group of NC blocks for a drilling operation in a CNC machining center, and the portion of a NC program generated for machining a hole

2.4. The Database

An important element in the FMS control software is the manufacturing system database, which should contain the information regarding the state of the whole manufacturing system. Some of this information should be updated manually by the FMS operator, as for instance the location of certain end mills in the magazine of the CNC milling machine. Due to this need, an interface is being developed so that the operator can introduce this information himself, and then it will be updated in the MySQL database (2002). The control software, as well as the CAPP system, will make decisions based on the information in this database. Examples of tables in this database are shown in figures 9 and 10.

AtribFeat_id	Diametro	TolDiametro	Comprimento	TolComprimento	Rug
1	20	0	30	0	1
2	12	0	20	0	999
3	10	0	15	0	999
4	20	1	30	0	999
5	12	0	20	0	999
6	12	0	20	0	999
7	10	0.2	10	0	5
8	10	0.2	10	0	5

[8 row(s) affected]

Figure 9. Table of features present in parts in the MySQL database

Fresa_id	Tipo	Material	Diametro	Ndentos	CompCorteAxial	CompCorteRadial	Qualidade
1	"Topo"	"Metal duro"	10	2	5	3	
2	"Topo"	"Metal duro"	12	3	5	3	
3	"Topo"	"Metal duro"	16	3	5	4	
4	"Topo"	"Metal duro"	20	3	6	4	

(4 row(s) affected)

Figure 10. Table of carbide milling cutters registered in the MySQL database

2.5. The Equipment in the FMS at SOCIESC

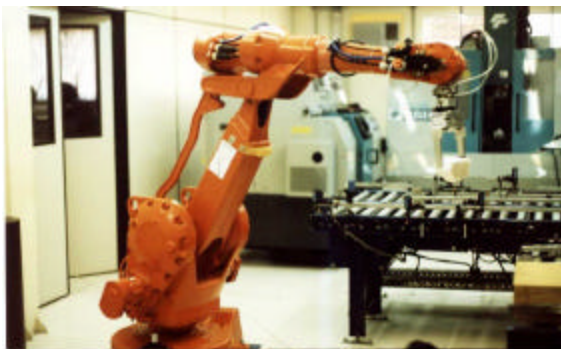
Figure 11 shows the pieces of manufacturing equipment that compose the FMS at SOCIESC. SOCIESC also has microcomputers responsible for exchanging information and equipment control.



(a) the FMS



(b) the CNC lathe and the CNC mill (both made by Feeler)



(c) the ABB IRB-2400 robot



(d) the automated storage and retrieval system (AS/RS) Scheffer

Figure 11. Pictures of the FMS equipment at SOCIESC

In the FMS, the robot, which is located in the center of the system, is responsible for picking parts from the AS/RS, and feeding them in one of the CNC machines; and the same robot removes the part of the machine and transports it to the other CNC machine, or back to the AS/RS (in the case the part is already in its final geometry).

Microcomputers are used in this integration, and the programs in these microcomputers execute the direct communication with each of the pieces of equipment in the cell, as well as with the upper level in the hierarchy. These microcomputers will be connected through Ethernet, and each microcomputer possesses a TCP/IP address.

Besides the microcomputers responsible for the direct communication with the equipment, there is another microcomputer that will be in the station level (see figure 3), which will be responsible for controlling the FMS activities. This last microcomputer corresponds to the "upper executor".

3. Conclusion

The work described in this paper has as one of its objectives to provide a high flexibility to a FMS, allowing a fast implementation of the FMS control software. In the case of physical alterations in the manufacturing system, the FMS operators themselves will be able to modify the software, reducing the time and the cost for maintaining the software.

The availability of a FMS to be used for producing parts via Internet leads to a significant approximation between the manufacturing company and the customer. Besides, the FMS site will enable the teaching of topics related to part manufacturing in automated systems, and this is important because, due to the high cost of FMSs, such systems are not usually available in Brazilian education institutions, and this could disseminate interest among youths toward this important area.

4. References

- Cybercut, 2000, "Cybercut Project", http://cybercut.berkeley.edu/html/design/webcad_user.htm
- Cyberlearning, 2003, "Cyberlearning.org - Quality Education for All", <http://www.cyberlearning.org>
- Dilts, D.M., Boyd, N.P. and Whorms, H.H., 1991, "The Evolution of Control Architectures for Automated Manufacturing Systems", *Journal of Manufacturing Systems*, Vol. 19, pp. 79-93.
- Ferreira, J.C.E., Steele, J., Wysk, R.A. and Pasi, D.A., 2001, "A Schema for Flexible Equipment Control in Manufacturing Systems", *International Journal of Advanced Manufacturing Technology*, Vol.18, pp 410-421.
- Ferreira, J.C.E. and Andriolli, G.F., 2001, "Uma Metodologia para a Fabricação de Peças à Distância", Congresso Brasileiro de Engenharia Mecânica (COBEM 2001), Uberlândia, MG, 26-30 November.
- Ferreira, J.C.E. and Andriolli, G.F., 2002, "Planos de Processos Contendo Alternativas: Uma Implementação Voltada para a Internet", Encontro Nacional de Engenharia de Produção (ENEGEP 2002), Curitiba, PR, 23 a 25 October
- Google, 2003, "Google", <http://www.google.com>
- Halevi, G., 1999, "Restructuring the Manufacturing Process: Applying the Matrix Method", St. Lucie Press.
- Lorini, F.J., 1993, "Tecnologia de Grupo e Organização da Manufatura", Editora da UFSC, Florianópolis, SC, Brazil.
- MySQL, 2002, "MySQL - The World's Most Popular Open Source Database", <http://www.mysql.com>
- Robosim Project, 1999, "Robosim", <http://www.ee.uwa.edu.au/~braunl/robosim/java>
- Saturn, 2003, "Welcome to Saturn", <http://www.saturn.com>
- Scientific American Frontiers, 2000, "21st Century Medicine: Cybersurgery", www.pbs.org/safarchive/4_class/45_pguides/pguide_605/4565_cyber.html
- Smith, J.S. and Joshi, S.B., 1993, "Message-Based Part State Graphs (MPSG) for Shop Floor Control," Proceedings of the 2nd IIE Research Conference, Los Angeles, USA, May 26-28.
- Smith, J.S., Hoberecht, W.C. and Joshi, S.B., 1996, "A Shop Floor Control Architecture for Computer Integrated Manufacturing", *IIE Transactions*, Vol. 28, No. 10, October, pp. 783-794.
- Spatial Technology, 2003, "Spatial", <http://www.spatial.com>
- Telerobot Project, 1998, "Australia's Telerobot on the Web", <http://telerobot.mech.uwa.edu.au>

5. Copyright Notice

The authors are the only responsible for the printed material included in this paper.