An Approach to Fixture Systems Management in Machining Processes

L. A. Consalter
Dept. of Mechanical Engineering
University of Passo Fundo
Passo Fundo, RS. Brazil
lac@upf.br

L. Boehs
Dept. of Mechanical Engineering
Federal University of Santa Catarina
Florianópolis, SC. Brazil
lb@grucon.ufsc.br

Starting from the premise that the management of fixture systems in the area of machining has been somewhat neglected from the standpoint of its technological development, the work reported on herein focuses on the development of a methodology for the management of these systems. Based on the findings of a survey carried out at companies operating in this sector and on a review of the literature on the subject, both of which confirm this lack, hypotheses are drawn up and supporting data compiled to underpin the development of a systematic, extensive and flexible model. The model, founded on principles of standardization and modularity, basically consists of four main stages: the company's definition/characterization of fixtures management, selection of the type of fixture suitable for the company, rationalization and organization of the area, and the construction of planning and control architectures within the company. We foresee that the formalization of the scientifically-based management support model proposed here will contribute significantly to productive and R&D sectors, computerizing the fixtures management methods used by companies and integrating their managerial philosophies and procedures for machining tools and fixtures.
Keywords*: Fixturing, machining, management*

Introduction

Among the many activities involved in machining manufacturing processes, the fixture of parts to immobilize them while they are being worked on is still one of the most problematic procedures. The level of abstraction for the solution of problems with fixtures is very high and is extremely dependent on the practical experience of process designers and operators. Over the years, this experience has failed to be adequately documented; hence, production processes continue to face difficulties and a paucity of solutions for old fixation problems that might otherwise have already been solved.

Even in the old systems of manual production, in which time and cost factors were not as important that they are today and a product's quality depended mainly on the craftsman's skills, there was already a need for better fixture design and utilization methods. The advent of mass production consolidated the standardization of parts, allowing for the use of unskilled labor and freeing the more experienced and skilled professionals for more complex work involving greater responsibilities. This was the main factor contributing to the current neglect of fixtures.

According to the paradigm of flexible production, productivity, cost, quality and flexibility are more than words; they are concepts that embody real factors such as the short life cycle of products, growing consumer demands, and ever shorter production times. These factors, in combination with the shift from paradigms of manual production to mass production and then to flexible production, have given rise to an increasing number of requirements, procedures and administrative concerns in the design and use of fixtures, so that these activities can no longer be taken lightly. Thus, there is an urgent demand for a systematic methodology for computer-aided fixtures management.

Fixtures management, which consists of the decisions and actions taken by a company with the primary purpose of reducing the costs and increasing the productivity of production processes, is an activity that involves the planning of resources and the use of fixtures from the technical, logistic and strategic standpoints. Technical planning decisions and actions involve the design and use of fixtures, with close interaction through technological information between the areas of design and processes, so that the parts to be fixed can be manufactured safely, with quality and at the lowest possible cost. The logistical aspect of this management involves the timely delivery of physical resources and information about fixtures to the right place. This requires a complete understanding of the company's situation and manufacturing capacity, encompassing its production, design, maintenance, warehousing, purchasing and its fixture or fixture component suppliers. Strategic planning decisions have to do with the expansion or reduction of the resource capacity of the company's fixtures area, and involve issues of standardization and modularization, as well as of rationalization and layout of the area, which usually implies new investments and new management philosophies.

According to Wiendahl (1994), the complexity of productive systems is the fundamental cause of many companies' management problems. The following facts were revealed in a survey carried out by Eversheim at German companies from 1975 to 1990: the diversity of parts increased by 400% during that period; production lead-times were up to 50% shorter; 60% of the product's lead-time was spent on the design and planning stages; and the factory's rate of technical utilization was a mere 60%.

The difficulties inherent to fixtures derive from the technological gap that separates them from the advances achieved in the production systems of which they are a part. In other words, although computer techniques such as CAD and CAM have been widely implemented, fixtures, which are situated at the interface between design and production, are still relegated to a secondary plane of relative importance, despite the substantial savings in investments and costs that these devices might represent for companies. According to Tomek, as quoted by Veeramani et al. (1992), the initial investment in fixtures and cutting tools may represent up to 25% of the investments made in a flexible manufacturing system (FMS). Moreover, according to Boyle, also as quoted by Veeramani et al. (1992), expenditures on fixtures and cutting tools represent seven to ten times the capital invested in a piece of equipment during its service life.

The use of fixtures is a complex activity involving many factors. The most obvious evidence of this situation is the large number of companies that still use manual, obsolete methods to define their fixturing procedures, based on dogmatic, sometimes improvised decisions. According to Nee et al. (1995), despite the gains in productivity attained through the automation of design routines and manufacturing tasks, almost 85% of all fixture process and design plans are drawn up manually, and detailed optimization plans are rarely made. Furthermore, efforts to solve fixture-related problems

Paper accepted March, 2004. Technical Editor: Alisson Rocha Machado.

have been limited mostly to the field of academic research and development, rarely focusing on practical manufacturing situations. Thus, optimization of fixture usage ranks high among the challenges that currently require urgent attention and technological development.

The problem of fixtures management in Brazilian companies was analyzed systematically and in full detail by Consalter and Boehs (2002), based on a qualitative scientific survey involving companies of the metallurgical and mechanical sectors in southern and southeastern Brazil. The authors concluded that "metallurgical and mechanical companies using machining processes tended not to engage in systematized fixtures management, possessing neither the technological resources nor the organizational strategies that would ensure the use of such systematization."

Given this situation, the present work proposes a systematized fixtures management model designed to help reduce the current fixture-related management problems of companies working with machining processes.

Bibliographical Review

The literature available on the theme of fixtures reports that the R&D efforts of recent years have focused almost solely on the design of these devices. Therefore, save for a few rare exceptions, the specialized literature scarcely addresses the organizational and technical-administrative issues that characterize fixtures management at all (Boerma, 1988; Hou & Trappey, 2001). This fact alone indicates the lack of scientific work devoted to fixtures management, reinforcing the need for and importance of development in this field. It is worth noting, however, that a large part of fixture-related activities and design also represent management tasks, particularly in the planning stage. This fact is illustrated in reference models of information integration (Hsu et al., 1995) and of machining and fixtures coordination planning (Teramoto et al., 1998).

The considerations of fixture design, mainly in the conceptual or planning phase, apply largely to its management, indicating a strong correlation between these two activities (Consalter, 1996). This is illustrated through an analysis, by the same author, of the several principles and criteria considered in fixture design and their correlation with manufacturing process activities. On this subject, Nee et al. (1995) state that "fixtures design is inseparable from the planning of the process; hence, for a CAPP system to have any practical usefulness, it must include fixtures design."

One of the first tasks of fixture planning is the selection of the assembly concept most suited to the intended application, which involves management of the criteria that influence the planners' decisions. The main criteria for fixtures selection are based on three interdependent factors (Carr Lane, 1995): costs, constructive details, and operation. In addition to these criteria, many characteristics must be analyzed, involving, according to Hoffmann (1998), the part to be fastened, the manufacturing process, the machine tool and the fixtures themselves.

Considering the benefits of modularity, particularly the aspects of flexibility and component interchangeability, Liu (1994 and 1995) developed a design methodology for the modularization of dedicated fixtures. This methodology is comprehensive, involving dedicated fixture classification tasks, the development of rules for modularized component assembly and modular fixation component design. According to Sosale et al. (1997), common modules can be standardized and produced in large batches, increasing the efficiency and quality of production and reducing costs, in addition to contributing to the company's overall standardization. In the opinion of Erlandsson et al. (1992), the increased modularity of a product produces positive effects on the total flow of information and materials, from its development and purchase to its stocking and delivery. Kusiak & Huang (1996) listed the following potential benefits of modularity: scale economy; greater viability of product/component exchange; increased product variety; reduction of lead-times, fragmentation of risks; easier diagnosis, maintenance and repairs, and greater product availability.

The 1990s saw the beginning of research and development of fixtures in computer programs dedicated to the solution of planning, selection, assembly, and fixture validation problems. The result was a variety of models based on computational programs with varying levels of automation, ranging from specialized systems based on different functional principles to sophisticated software programs for structural analyses (Kumar et al., 1992; Siong et al., 1992; Pereira and Cunha, 1996; Hirsch et al., 1994; Yue and Murray, 1994; Ngoi and Leow, 1994; Sayeed and Meter, 1994).

With regard to fixture classification and coding, Liu (1995) considers that a large part of the skills of experienced design engineers is not easily passed on from one generation to the next because these devices have usually been improperly classified or because their functional parts have been unclearly specified. The literature contains information on procedures for classifying fixture types according to their application, process and machine tool type (Carr Lane, 1995). However, the procedures are mostly limited to only one subdivision, rendering such classifications too generic. In practice, each modular fixtures manufacturer uses its own codification system for most of the fixture components it produces (Carr Lane, 2002 and Erwin Halder, 2002) and another code standardized by an institution such as AISI or DIN.

Nee et al. (1995) also used the technology of features resource to develop a fixtures classification methodology to aid design tasks.

The literature proposes a fixtures classification based on the fixture's application (Carr Lane, 1995), which, in principle, appears to be the most suitable one for management purposes. According to this approach, fixtures are classified into the following categories: Permanent (or Dedicated), General-Purpose and Modular, the main distinction factor in this classification being the cost/benefit ratio between the fixture and the manufacturing process.

Hypotheses and Model Development Methodology

The problem of fixtures management and concerns about its solution are embodied within a scenario of great diversity of fixture types, a multitude of design and manufacturing requirements, and administrative procedures that generate huge volumes of information. Two hypotheses are therefore proposed for fixtures management, as described below.

Based on the difficulties caused by the complexity and diversity of physical components and information in fixtures management, the first hypothesis of this work is the following:

"Using an appropriate methodology, the conception of dedicated and general-purpose fixtures can be transformed at least partially into modular fixtures, thereby facilitating the systematization of the managerial procedures for this area."

The approach of this hypothesis is based on principles of fixture standardization and modularity, which give one a limited set of types of these devices. To this end, methodological procedures of standardization and modularity are developed and discussed in and with the company, representing the first primary goal of this work.

The aforementioned hypothesis supports a possible solution for the problem of fixtures management, which is expressed in our second hypothesis:

"By adopting the principles of standardization and modularity, one can develop a systematized management model that it is adaptable and applicable to the diverse types of fixtures, as well as to different machining processes, products and production systems."

The second hypothesis gives rise to the following question: What should this management model be like from the user's standpoint? In other words, from the standpoint of those who live with the problem, develop specific solutions and accumulate experiences. It is therefore crucial that, in addition to theoretical precepts, information be compiled regarding the procedures used during the use of fixtures. The second primary goal of this work is thus identified as the development of the fixtures management model, which is based on technical and administrative procedures employed by companies of the metallurgical and mechanical sectors in their machining manufacturing processes.

Synthesis of Fixture Information and Resources

This synthesis starts from the premise that management procedures should be developed based on a company's individual characteristics, so that their implementation does not cause problems and their functional identity is maintained. However, in order to systematize the management of fixtures systems in a company with a diversity of management characteristics, the fixture resources must be synthesized. Hence, the procedures for each company must be directed specifically towards its profile while simultaneously providing a comprehensive system to manage these resources. To synthesize the fixture resources, the components with specific functions are conceived and considered as standardized modules. These modules are composed of specific groups of components, forming a limited group of predominantly modular fixture types that adequately match the company's profile according to its particular characteristics. It should be noted that what renders this synthesization effective is the application of the principles of modularity and standardization on the fixture resources, a fundamental requirement for the proposed management model. A methodology for standardization and modularity that is applicable to this fixtures management model was developed by Consalter (1999).

The work of standardization and modularity directs the application of fixtures to better-defined fields, while simultaneously broadening their range of applications. Fixtures can therefore be grouped into new subclasses to fit the different profiles of production systems. Division into application subclasses contributes to the selection of types of fixtures, so that the best application can be chosen according to the production systems' characteristics. Based on this premise, Consalter (1999) developed the fixtures taxonomy illustrated in Fig. 1.

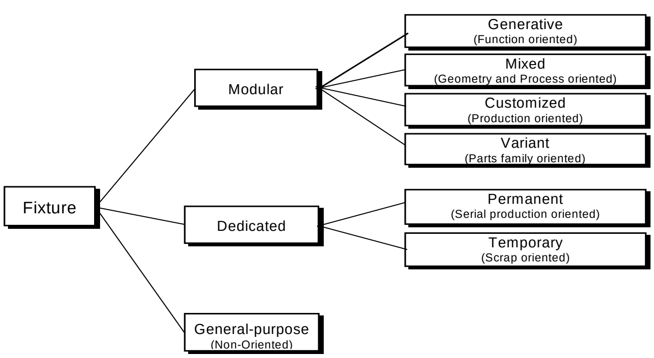

Figure 1. Taxonomy of fixtures.

This taxonomy shows a clear predominance of modular fixtures among the subclasses, which contributes significantly to the systematization of management in this area.

Architecture and Description of the Model

Based on fixture standardization and modularity, a management model is proposed having the following characteristics:

- Comprehensiveness: offering options for the management of resources and procedures of a variety of production systems;
- Adaptability: based on the company's needs, the model formalizes the requirements of fixtures management without altering the company's original identity, resources and strategies;
- Modularity and standardization: from the start, the model addresses the managerial process of fixtures in a systematized manner;
- Managerial optimization: from the standpoint of fixtures, the model contributes toward the organization and rationalization of several departments in the company;
- Logical and sequential orientation: the fixtures management process is organized into chronological stages that then become dependent and interlinked;
- Improvement and adjustments: the model allows for revisions and alterations to be made in any stage to adjust the fixtures management system to the company's changing needs and strategies;
- Support: the model allows for the use of tools or techniques to support the development of each stage of the management methodology;
- Automation: computer-aided operational structure;
- Interdepartmental integration: the model facilitates communication and integrates the procedures of different areas in the company.

The proposed model consists of four stages, constituting a systematic optimization of the fixtures area that takes place in two phases, the first one organizational and the second administrative. Fig. 2 illustrates the model's architecture, which is described below.

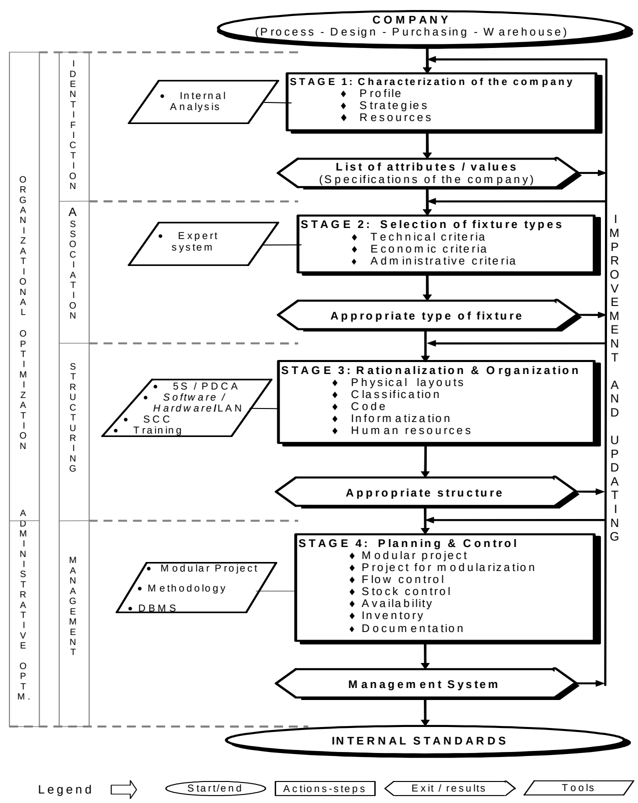

Figure 2. Model of the fixtures management system.

As can be seen in Fig. 2, the organizational optimization phase is divided into three phases, corresponding to the activities of identification of the company, association of fixtures with the company's profile, and structuring of the fixtures area. The purpose of the identification phase, which consists of compiling the list of attributes and values that characterize the company in terms of correct fixtures application, is implemented in stage 1. The purpose of the association phase, which is to define the type of fixture that best fits the company's characteristics, is implemented in stage 2. The structuring phase, which focuses on preparing the company in terms of its physical and human resources for the introduction of its new managerial fixtures concept, is implemented in stage 3. The administrative optimization phase takes place in a single stage consisting of the fixtures management itself, which is implemented after the company's preparations are completed. This stage, which directly involves the use of the company's fixtures and whose objective is to provide systematized planning and control procedures, is implemented in stage 4 of the model.

Each of the model's stages consists of a set of steps representing the procedures that determine the management systematics, and should therefore be part of the company's internal standards and procedures. At the end of each stage, the results are evaluated and compared against the respective goals. Should the results of a stage prove inconsistent with the stated objectives, its procedures are altered to improve or update them, after which the subsequent stage is initiated.

Stage 1: Characterization of the Company

The characterization of the company for fixtures management purposes involves the compilation and grouping of information on the company's fixtures resources, requirements and strategies. This information will later serve as the basis for technical and economic analyses for the selection of fixtures, and is expressed in the form of attributes, together with their respective values. The following examples can be cited to illustrate pairs of attributes/values: production_type/FMS; part_weight/15 kg. Therefore, this stage consists of identifying and compiling the company's internal information, based on a list of predefined attributes with pre-specified value options.

To ensure a representative characterization of the company's resources and director plan from the standpoint of fixtures area management, the quantification of the attributes must include strategic, logistic and technical planning, such as standardization, cost reduction, etc. (strategic planning); machine capacity, fixture identification and availability, storage, etc. (logistics planning); machining conditions, cutting tools, assembly of fixtures, etc. (technical planning). This implies the participation of several sectors and all the hierarchical levels of the company.

Stage 2: Selection of Fixtures

This stage consists of choosing the type of fixtures that offer the best technical, economic and administrative solution for the company, based on the attributes and values established in stage 1.

The first step in this stage, therefore, is to draw up a decision chart for the selection of fixtures, which, in principle, has already been defined by the taxonomy of fixtures shown in Fig. 1, to which new subclasses of lower instances can be added if it is desirable to present the selection process in greater detail.

A second very useful step is the development and implementation of a specialized system for the selection of fixture types. The system's formalization consists of specifying the software (shell) and defining how the knowledge is to be represented. A highly relevant key aspect of this implementation is the correct formulation of the guidelines that define the type of fixtures. These guidelines are determined by establishing the attributes and values that are necessary and sufficient to identify unambiguously each subclass of the decision chart and, hence, the type of fixture best suited to the application. It is, therefore, a process of matching the company's characteristics with the types of fixtures, which is carried out by knowledge rules.

Stage 3: Rationalization and Organization of the Fixtures Area

Rationalization and organization of the area of fixtures, within the scope of this work, are consecutive actions applied to the following company resources: fixtures and their components, technological and administrative information; people; computers and software. The results of this rationalization and organization should not lead to disruptive changes in the company's resources, but, instead, place them under a new perspective. The parts to be fastened may undergo minor alterations in design to facilitate fixture modularity and standardization.

Rationalization of the Fixtures Area

Rationalization of the area of fixtures consists of reducing the number and variety of fixtures and fixture components and the information about them. This reduction is based on the type of fixtures selected earlier in stage 2 and on production requirements and capacity. There are four possible ways to rationalize the area of fixtures, depending on how the available resources match the new type of fixtures selected, and these four ways should serve as basic guidelines for the rationalization.

The first possibility is the gradual transformation of the fixture components or the dedicated fixtures into modular devices. This transformation is appropriate in the following situations:

- If the selected fixture is of the Dedicated-Permanent type and the company does not adopt modularization or modular design;
- If the selected fixture is of the Modular-Mixed type, since its non-modular components must be modularized;
- If the selected fixture is of the Modular-Customized type and a special component is required because the fixture must be modularized.

The second possibility is the partial substitution of the fixture components or of the fixtures themselves, which is applicable in the following situations:

- If the selected fixture is of the Modular-Generative type and the company uses both Dedicated and Modular components or fixtures in the same productive system;
- If the company uses only General-Purpose type fixtures, regardless of the type selected.
- Another possibility is the total substitution of the components or the complete fixtures, which is the case when:
- The selected fixture is of the Dedicated -Temporary type;
- The selection indicates the use of any type of Modular fixture, but the company uses the Dedicated-Permanent type fixture;
- The company already owns the fixture components or fixtures that match the selected type, but they do not meet the process requirements completely because they are damaged, worn out, technologically obsolete, or their size and shape is unsuitable.

A fourth way to rationalize the fixtures area, which can be carried out simultaneously with any one of the aforementioned possibilities, is through the partial elimination of components or of the fixture. This situation is applicable when:

- The company possesses the components or fixtures that match the selected type, but some of them are damaged, worn out, obsolete or their sizes and shapes are inappropriate;
- The company owns more components or fixtures than required to meet the needs of its production system.

In short, rationalization of the fixtures area involves redefining its resources so that the process of organization can begin, according to the type of fixture, focusing on the systematic management of the area.

Organization of the Fixtures Area

The purpose of organizing the fixtures area is to provide and arrange the physical resources and information involved with the pre-selected fixtures, so that their operation can proceed logically and systematically within the ambit of the company. Basically, the organization of the fixtures area is based on four procedures, i.e., the area's physical layout; classification and codification systems for the fixtures; fixture computerization within the company; and qualification of the human resources involved.

With regard to the physical layout of the fixtures area, one must begin by considering that each type of selected fixture corresponds to a company profile or a production system. The model of the physical layout is based on this profile so that the administrative requirements of fixtures and their components are satisfactorily met. This means that the location and configuration of the warehouse, the assembly lines and the fixtures control area must be correctly defined. Thus, based on the pre-selection of fixture types, the basic guidelines and recommendations for the physical layout of the fixtures area are as follows:

- If the selected fixture is of the Modular-Generative, Modular-Mixed or Modular-Customized type, or if the components are entirely or even mostly modular-commercial, the following should be available:
  - A central warehouse, preferably adjacent to the tools warehouse;
  - General control of fixtures and their components in the central warehouse itself;
  - Assembly of fixtures inside the central warehouse.
- When the selected fixture is of the Modular-Variant type, there should be:
  - A sectorial warehouse organized according to allocation by group or production cell;
  - The overall control of fixtures and components should be centralized in Process Engineering;
  - Assembly should be carried out in the cell adjacent to the sectorial warehouse.
- When the selected fixture is of the Dedicated-Permanent type, the following is recommended:
  - The fixture, with its components mounted or not, should be located next to its respective production line. Depending on the size of the fixture, it should be stored in a cupboard or in a physically protected area;
  - General control of fixtures and possible components located in the production line area, supervised by Project Engineering;
  - Assembly should be carried out in the tool shop if the fixture's design and construction are not outsourced.
- If the selected fixture is of the Dedicated-Temporary type, the following is recommended:
  - Dispense with fixtures warehouses or deposits;
  - Have Project Engineering carry out the general control of fixtures;
  - Carry out assembly work in the tool shop if the design and construction of fixtures is done in-house.
- When the selected fixture is of the General-Purpose type, the following are necessary:
  - Have a central warehouse, which may be the same as the one used for Modular-Generative, Modular-Mixed or Modular-Customized type fixtures, should one of these three types be selected.
  - Perform the overall control of fixtures inside the central warehouse itself;
  - Does the assembly work inside the warehouse.

The fixture-related information requires an organizational structure to allow for its systematic management, particularly if it is computer-aided, as in the case of the proposed model. This implies the systemic organization of technological, geometric and administrative information so that it can be transformed into a logical and operational representation. This organizational structuring of information is accomplished through the conception and development of a Classification and Codification System (CCS) for the items to be managed, i.e., the fixtures and their respective components. For purposes of fixtures management based on the proposed model, the main objectives of the CCS are as follows:

- Provide a flexible CCS aimed at a versatile and computerized application;
- Activate the flow of information regarding fixtures and enhance its understanding;
- Facilitate the identification and control of fixtures and their components within the confines of the company;
- Organize communications regarding fixtures among the company's sectors and at fixtures manufacturers;

The fulfillment of these objectives results in a CCS of fixture components such as the one developed by Consalter (1999). In this CCS, a code is assigned to each end item of the different fixture component families. The conception of these codes is designed to meet the requirements of fixtures management both in computational systems and by conventional manual means.

Thus, a code stating *BAS/PLA/HOL/HOR-SQU/S400-HAL/15002*, for instance, represents the following component: Plane horizontal base, composed of holes, square shaped, with 400 mm long sides, supplied by the company Halder under code 15002.

Once the physical layout is structured and the resources of the fixtures area rationalized, the next step in the task of organization is to supply the means to computerize the area for management purposes. At the company level, the fixtures data and information must be generated, stored, processed, transmitted and made available. In most cases, this involves several sectors of the company. It is therefore essential for the company to have a computerized system that is consistent and comprehensive. The first step in this direction is to allocate PCs to each of the sectors that handle and/or process information involved in the fixture's life cycle. Naturally, the fixtures area must be equipped with a database and its respective management software. The third step required to computerize the company's fixtures management is to link these PCs to a local network server in order to integrate the areas of Purchasing, Process Engineering, Project Engineering, Warehouse and Central Administration.

Structuring the company to implement a new management methodology requires adaptations to be made in human resources and its customary procedures. Although companies implement such alterations to differing degrees, training and refresher courses are required, in every case, to qualify the employees involved with fixtures to handle the new managerial situation. This means that an ongoing training and awareness program is required. Another human aspect that is important for systematic fixtures management is the need to place the administrative responsibility of the fixtures area into the hands of a single person. Whether this involves a full-time or part-time activity will depend on the company's characteristics and strategies. This person will be responsible for the overall management of the fixtures area, coordinating and controlling it.

Once the company's fixtures area has been rationalized and organized based on its characteristics, it is potentially structured to assimilate a systematized form of management that allows for the administrative optimization of the area, which takes place in the last stage of the proposed model.

Stage 4: Planning and Control of the Fixtures Area

Fixture planning and control activities are interrelated managerial procedures whose common purpose is to optimize the use of fixtures and their effects on the company's manufacturing processes. These activities consist of a set of design and administration activities considered essential and complementary to fixtures management.

The essential activities are those that take place each time a new fixture assembly layout is required and that are continuous and interactive with the application and existence of fixtures in the company. These activities have a direct and immediate effect on the production performance and quality of the fastened parts. Among the activities essential to fixture planning are modular design processes, assembly procedures, integration of information among the factory's sectors, and the selection of fixture types carried out in stage 2 of this model. Insofar as fixture control is concerned, the essential activities consist of monitoring the flow of fixtures and their components, controlling their availability and stock, their documentation and their inventory.

The complementary management activities, on the other hand, are independent of new fixtures assembly layouts. These activities consist of procedures to support the qualification and availability of fixtures, and are carried out in parallel and without interacting with the fixtures used in production. These activities may, however, indirectly affect the quality of the parts and the performance of production, depending on how they are carried out operationally. The complementary activities of planning and control involve the operational procedures of maintenance, inspection, transport, cleaning and protection of the fixtures and their components.

Fixture planning, in its broadest sense, consists of a design process based on the needs of usage. Thus, following the line of this work, fixture planning aimed at its systematized management in the company as a whole is achieved through the application of modular design and modularization project methodologies that are also systematized. It is precisely through this application that fixtures are implemented in a company, in agreement with the philosophy of standardization and modularity. In other words, it is through this action that Modular-Generative and Modular-Customized type fixtures are confirmed in their respective companies with their originally modular conceptions. The components of the Modular-Mixed and Modular-Variant type fixtures are thus transformed into modules with standardized interfaces, while the components of the General-Purpose fixtures are classified as modules. In this way, each module comprising one or more fixture components represents a properly classified and identified individual item, and is thus easily managed or controlled using a database management system (DBMS).

Because a new part to be fastened implies a new fixture layout, and considering that each part type or its variants represents a product for which a design was developed, an analogy can be made between a fixture and a product and, thus, the modular system design methodology can be adopted (Maribondo, 2000) to carry out the systematized planning of fixtures.

From the management viewpoint, the control of fixtures consists of a set of computer-ordered activities aimed at minimizing disruptions in the productive process and optimizing the use of company resources. Thus, the use of pertinent and continually updated fixture-related information enables the movement of all the fixture components in the company to be controlled, with permanent online monitoring of their path through the factory, their current location, the situation of fixture stocks, fixture and component purchasing, replacement or repair requirements, and inventory updating. In addition, the technical data and information on components listed in the system are available to authorized personnel, enabling them to make searches for specific purposes, such as the selection of components for fixture planning and assembly.

The application of the modular systems design methodology allows fixture components to be considered as items, regardless of their type. Coupled with this, the use of the CCS developed in stage 3 of the proposed model allows for the computerized identification of fixture components. Thus, it is possible to control the company's fixtures using a DBMS configurable for the different types of productive systems and in accordance with their characteristics. Each of these types has its own architecture of information flows and physical entities upon which the appropriate control model is applied. A control model corresponds to a standard set of procedures adopted for this purpose within the domain of each fixture type, according to the taxonomy shown in Fig. 1. These models are governed by the way the fixture types match the company's characteristics and by the resulting rationalization and organization of each fixture in its area, as described in stages 2 and 3 of this management model.

The systematized and computerized managerial control of fixtures applied to machining processes is guided by the characteristics of the different types of fixtures utilized in a factory. The diversity of fixture-related technical, functional, logistic and strategic characteristics renders it unfeasible to use a single management system. Therefore, flow architectures representative of each type of fixture are required, in which a systematized treatment of control can be implemented through the physical entities and information concerning given types of fixtures. This representativeness is founded on the preservation of the company's functional and strategic identities and on minimal interference in its fixtures area. Figs. 3 and 4 depict two flow architectures for the control of Modular-Generative and Dedicated-Permanent type fixtures, respectively.

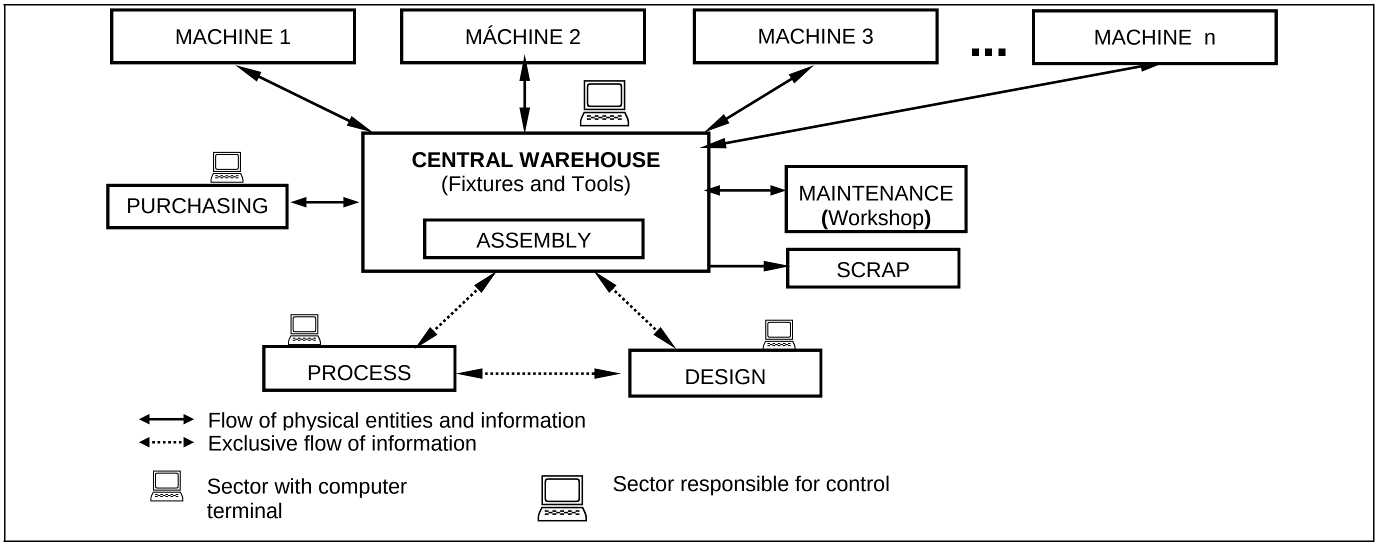

Figure 3. Flow architecture for control of Modular-Generative fixtures.

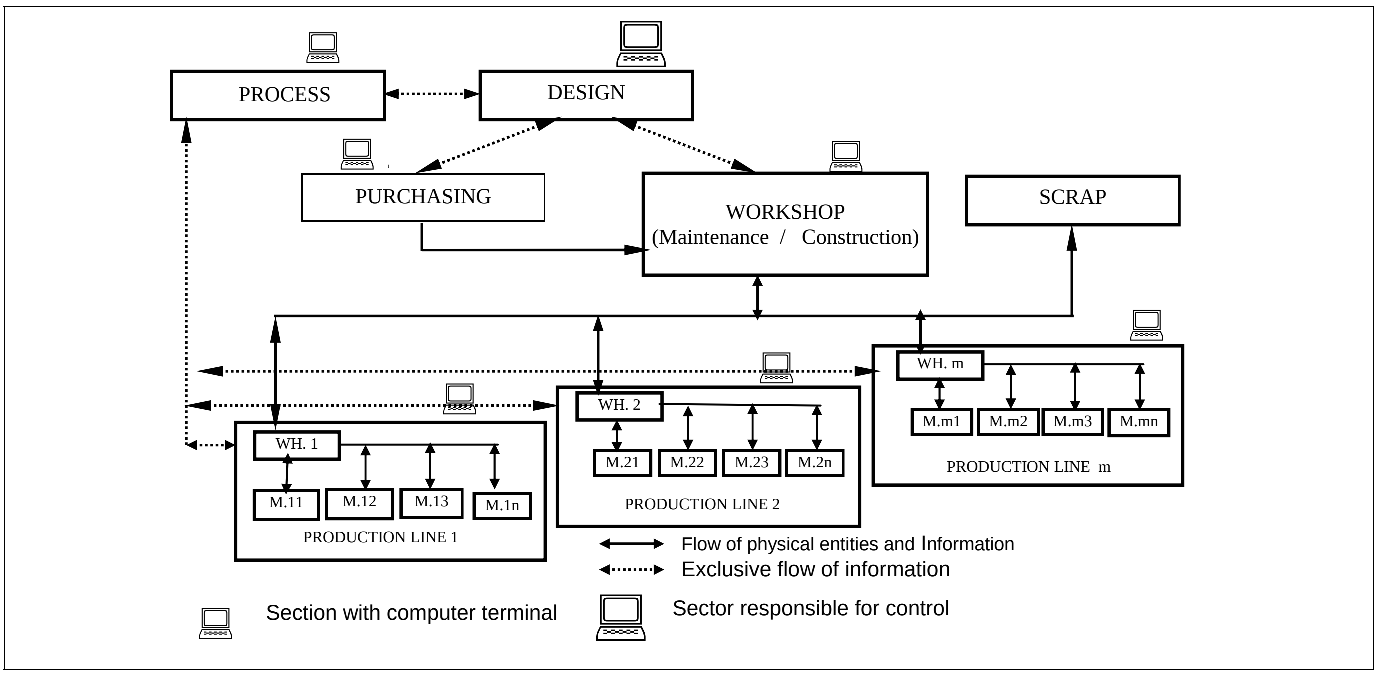

Figure 4. Flow architecture for control of Dedicated-Permanent fixtures.

The management models developed for each type of fixture are fairly flexible in terms of conception, and their flow architectures can be adjusted both from the standpoint of sector configuration and from that of physical entities and information flows. However, the essence of the structure of the management model for each type of fixture should not be altered, for such modifications might lead to a loss of systematization capacity.

Strictly speaking, a company can use different coexisting fixtures management models, provided the DBMS utilized is adequately configured in terms of the limitations and attributions of the different sectors involved. Thus, a company structured into production lines with flow architectures configured for Dedicated-Permanent type fixtures, for example, can have its Tool Shop operating according to Modular-Customized type fixtures, provided it is subordinate to a single control sector previously configured in the DBMS.

Modularity is a constant factor in every fixtures management control model, and its predominance facilitates the management and control of the area by allowing for systematization and, hence, for information processing. Together with the issue of modularity, the integration of cutting tools and fixtures warehouses is an important step that contributes positively to the systematization of computer-aided management on the shop floor, using a single DBMS.

Conclusions

With the availability of a systematic standardization and modularity-based methodology for fixtures management, the requirements of fastening of new parts to be machined should no longer be viewed merely as generally burdensome activities of new fixture design and production. Instead, they should involve planning of the layout for a new assembly line, using available methods and resources, and represent gains in productivity and costs.

Because of the complexity of its functions and the lack of attention it has received, the area of fixtures has invariably been relegated to a secondary level of importance. This situation can now be inverted by applying the model developed and proposed herein, which offers a broad and flexible methodology, contributing effectively to the implementation of a system that encompasses the technical, logistical and strategic aspects of a company's fixtures throughout their life cycles.

The concept of the management model proposed here involves the use of a DBMS with information flows transmitted through a computer network, making the information easily available to different sectors of the company. It is therefore an element conducive both to the practice and consolidation of Simultaneous Engineering in the company. This conclusion takes into account that the information required for fixtures planning activities, with emphasis on their conceptual design phase, is interlinked with the design activities of the part to be fastened, as well as with machining process planning and with the selection of cutting tools, thus requiring the interaction of different sectors of the company.

The analysis of information based on correctly classified and encoded fixture items leads to the application of a single organizational approach to the information flow among the sectors that deal with fixtures and cutting tools, and to the integration of their procedures and managerial resources. This scenario offers an even greater simplification of the managerial process. In this context, simultaneous management of the company's cutting tools and fixtures on a single computational platform is feasible.

Although the model presented and discussed herein focuses on machining processes, its underlying philosophy can be applied to other production and control processes, such as welding and metrology.

References

Boerma, J.R., Kals, H.J.J., 1988, "FIXES, A System for Automatic Selection of Set-ups and Design of Fixtures", Annals of the CIRP, Vol. 37, No. 1, pp.443-446.

Carr Lane Mfg Co., 1995, " Jig and Fixture Handbook", 2.ed., Ed. Carr Lane, St. Louis, USA, 430p.

Carr Lane Mfg Co., 2002, "Online Catalog", St. Louis, Information by Internet, http://www.carrlane.com/oncatfrm.html

Consalter, L. A., Boehs, L.A., 2002, "The Situation of Fixture's Management in Brazilian Companies", (In Portuguese) Proceedings of the 10th Chilean Congress of Mechanical Engineering, 2002, Santiago of Chile, CD-ROM.

Consalter, L.A, 1999, "Development of a Methodology for the Management of Workholding in Machining Processes Based in the Standardization and in the Modularity", (In Portuguese), Ph.D. Thesis, Federal University of Santa Catarina, Florianópolis, S.C., Brazil, 227p.

Consalter, L.A., 1996, "Introduction to the Project and Management of Workholding Systems" (In Portuguese), Monograph, Federal University of Santa Catarina, Florianópolis, S.C., 114p.

Erlandsson, A., Erixon, G., Östgren, B., 1992, "Product modules – the link between QFD and DFA?", The International Forum on Product Design for Manufacture and Assembly, Newport, Rhode Island, pp. 1-20.

Erwin Halder Kg, 2002, "Unsere oline-kataloge", Achstetten-Bronnen, Information by Internet, http://onlineshop.halder.de/de/index_e4.asp

Hirsch, B.E., Thoben, K.D., Hämmerle, E., Nordloh, H., 1994, "CAD/CAM Integration of Fixture Planning for Nonprismatic Parts Based on Fixturing Features", Proceedings of IFIP International Conference, Valenciennes, Vol. 2, Valenciennes, pp. 803-815.

Hoffman, E.G., 1998, "Fundamentals of Tool Design",. Ed. SME, Dearborn, Michigan, USA, 755p.

Hou, J. L., Trappey, A. J. C. , 2001, "Computer-Aided Fixture Design for Comprehensive Modular Fixtures", International Journal Production Research, Vol. 39, No.16, pp. 3703-3725.

Hsu, C., Cho, J., Rattner, L. , 1995, "Core Information Model: A Practical Solution to Costly Integrating Problems", Computers and Industrial Engineering, Vol. 28, No. 3, pp.523-544.

Kumar, A.S., Nee, A.Y.C., Prombanpong, S., 1992, "Expert Fixture-Design System for an Automated Manufacturing Environment", Computer-Aided Design, Vol. 24, No. 6, pp. 316-326.

Kusiak, A., Huang, C.C., 1996, "Development of Modular Products", IEEE Transactions on Components, Packaging, and Manufacturing Technology – Part A, Vol. 19, No. 4, pp. 523-538.

Liu, C. , 1995, "A Gradual Transformation from Dedicated Fixture System to Modular Fixture System", Bulletin of the College of Engineering, N.T.U., Taipei, pp.97-109.

Liu, C. , 1994, "A Systematic Conceptual Design of Modular Fixtures", The International Journal of Advanced Manufacturing Technology, Vol. 9, p.217-224.

Maribondo, J.F., 2000, "Development of a Methodology of Systems Modular Project Applied to Processing Units of Home Solid Residues", Florianópolis. (In Portuguese), Ph.D. Thesis, Federal University of Santa Catarina, Florianópolis, S.C., Brazil.

Nee, A.Y.C., Whybrew, K., Senthil Kumar, A., 1995, "Advanced Fixture Design for FMS", Ed. Springer-Verlag, London, U.K., 204p.

Ngoi, B.K.A., Leow, G.L. , 1994, "Modular Fixture Design: A Designer's Assistance", International Journal Production Research, Vol. 32, No. 9, p. 2083-2104.

Pereira, G.M., Cunha, G.D., 1996, "Computer Aided Analysis of Requirements for a Fixture Project System" (In Portuguese), Máquinas e Metais, No. 364, pp. 98-106.

Sayeed, Q.A., De Meter, E.C. , 1994, "Machining Fixture Design and Analysis Software", International Journal Production Research, Vol. 32, No. 7, pp. 1655-1674.

Siong, L.B., Imao, T., Yoshida, H., Goto, K., Kou, L., Lim, D., Chin, L, Gan, C, 1992, "Integrated Modular Fixture Design, Pricing and Inventory Control Expert System", International Journal Production Research, Vol. 30, No. 9, pp. 2019-2044.

Sosale, S., Hashemian, M., Gu, P., 1997, "Product Modularization for Reuse and Recycling", ASME, In: Concurrent Product Design and Environmentally Conscious Manufacturing, Vol. 5, pp.195-206.

Teramoto, K., Onosato, M., Itawa, K., 1998, "Coordenative Generation of Machining and Fixturing Plans by a Modularized Problem Solver", Annals of the CIRP, Vol.47, No.1, pp.437-440.

Veeramani, D., Upton, D.M., Barash, M.M., 1992, "Cutting-Tool Management in Computer-Integrated Manufacturing", The International Journal of Flexible Manufacturing Systems, No. 3/4, pp. 237-265.

Wiendahl, H.P., Scholtissek, P., 1994, "Management and Control of Complexity in Manufacturing", Annals of the CIRP, Vol. 43, No. 2, pp.533-540.

Yue, Y., Murray, J.L., 1994, "Validation, Workpiece Selection and Clamping of Complex 2.5D Components", In: Shah, J.J., Nau, D.S. "Advances in Feature Based Manufacturing", Ed. Elsevier Science B.V., Amsterdam, Holland, pp. 185-213.