7

The GRAI-GIM reference model, architecture and methodology

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The GRAI models [1–3] give a generic description of a manufacturing system while focusing on the details of the control part of this system. The control of a manufacturing system will be presented first from a global point of view and afterwards at the level of the decision center.

In order for this description to be generic enough to be usable for any type of manufacturing system, the theoretical part is very important.

The work on the GRAI-GIM methodology started in the 1970s at the GRAI Laboratory of the University of Bordeaux. The objectives at that time were to model a production management system in order to be able to define precisely the specifications needed to chose a software package for a Computer Aided Production Management (CAPM) system.

At that time GRAI already worked closely with industry and we were surprised to learn of the difficulties involved in introducing CAPM packages in Industry. Our first conclusion was that people gave too much attention to the term C.A. (Computer Aided) and less to the term P.M. (Production Management). Coming from the field of Automatic Control we knew that the first task before us in introducing Automation was that of the modelling of the system concerned.

The original GRAI Model was first developed to help the designer to model a Production Management System. With the subsequent development of CIM systems, we have extended the same GRAI model to the whole Manufacturing System and have extended the GRAI Method to the design of such a CIM system. This became GIM (GRAI Integrated Methodology).

The domain of GRAI-GIM is to support the designer of a CIM system to help him elaborate the model of an Integrated Manufacturing System in

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order to deduce the specifications of that CIM system. These components will either be bought or developed in house.

The need for a methodology to design a CIM system is clearly based on the concept of a CIM system as presented below: A CIM system

- Can not be bought
- Must be build for each enterprise
- Must be developed based on existing and reliable components.

The development of GRAI-GIM was carried out in close cooperation with Industry.

The first application of the GRAI method (for Production Management) was made in 1980 with Telemecanique Electrique. Between 1980 and 1985 thirty other applications of the GRAI method were realized either by the GRAI Laboratory itself or by other Engineering firms.

In 1985, SNECMA, one of the most important manufacturers of Aircraft Engines used the GRAI method to design and specify the production management system of a Flexible Factory in Le Creusot, France.

In 1986, the GRAI Laboratory started to work on ESPRIT (European Strategic Programme for Research and Development in Information Technology) projects. Further development of the GRAI method has been carried out within this framework. The results obtained after several projects (Open CAM System (1986), IMPACS (1989), FOF (1989), Flexquar (1992)) have been the extension of the GRAI method to GIM (GRAI Integrated Methodology).

Today, there also exists the organization called AUGRAI (Association of the Users of GRAI Method) with about twenty industrial members (SNECMA, Aerospatiale, Cap Gemini, Pechiney, etc) which supports the further development and the promotion of GRAI-GIM.

If we compare the GRAI model to other architectures we find some similarity with the CIMOSA architecture concerning their concepts of views. The presentation of GRAI-GIM contains three parts:

- Conceptual reference model called GRAI
- Formalisms to describe the GRAI model
- Structured approach.

7.1 THE GLOBAL MODEL

From the considerations expressed above, we can say that a manufacturing system may be split into two parts (Fig. 7.1):

- On the one hand the physical system composed of the people, facilities, materials and techniques which has the aim of transforming the raw material components into a final product in order to add value to the material flow:

- On the other hand the control system whose purpose is to control the physical system in accordance with the objectives defined.

The control system can also be split into two subsystems (Fig. 7.2)

- A decision system
- An information system.

The goal of the first one is to make the necessary decisions in order to define the orders to be transmitted to the physical system; the second one enables the transmission, processing and memorization of the information needed. It acts as a link between the physical and the decision systems and with the environment as well.

The decision system and the information system are strongly linked. Thus a close synchronization between them goes far to assure the efficiency of the control system.

When a system has a high level of complexity it can be efficiently controlled by the implementation of a hierarchical control system. The management theory of such a system introduces three typical levels which are: strategic, tactical and operational ones (Fig. 7.3). In such a system each level must be coordinated by the next upper level.

Another aspect we have to take into account is that coming from classical management theory which emphasizes the functional decomposition of a such system. This approach presents several functions (the number being related to the complexity of the company) which are closely linked to the organization of the company according to services being performed. This

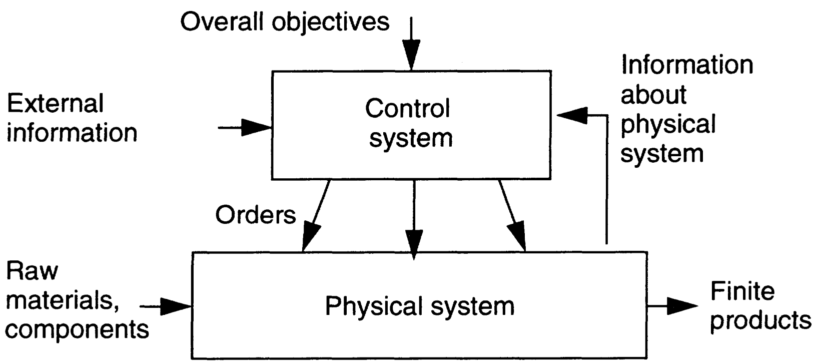

Figure 7.1 Splitting of a manufacturing system.

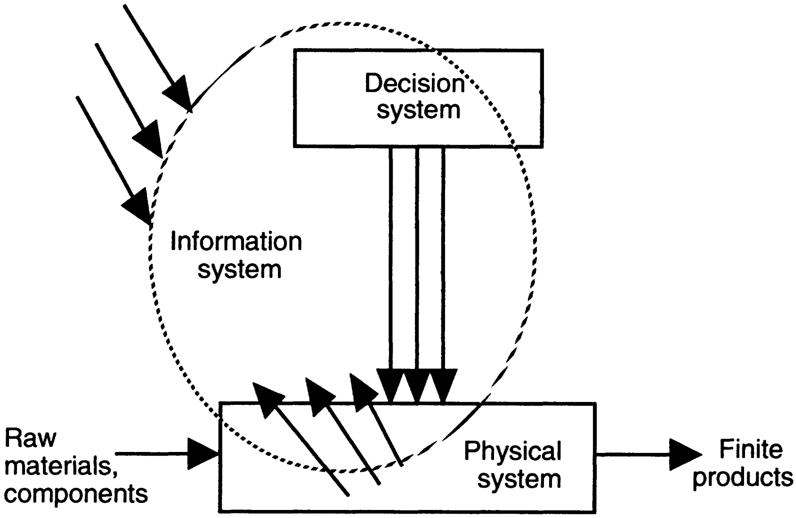

Figure 7.2 The decision and information systems.

approach then brings us a decomposition into three main functions: the resources management, the product management and the planning.

The first one is related to the transforming entities (the resources) which are made available by the structure of the system. The second one is linked to the major purpose of the factory system which is the transformation of products coming from the environment into new products for the environment. The planning function aims at coordinating all of the system by taking into account the global objectives of the company and making compromises between the workings of the other two functions as necessary (Fig.7.4).

The concept of feedback must be put into this model. Controlling the physical system without feedback means that the control system does not know the current status of the resources. Because the control system is hierarchial, all information from the physical system must move to each control level through the filter and aggregation functions of the level below (Fig.7.5).

When defining the control system of any manufacturing system these considerations lead us to propose a two dimensional decomposition:

1. A functional decomposition (vertical divisions), defining the various functions of such a system for each major part.
2. A hierarchical decomposition (horizontal divisions) in accordance with the time criteria of instituting decision making levels which are

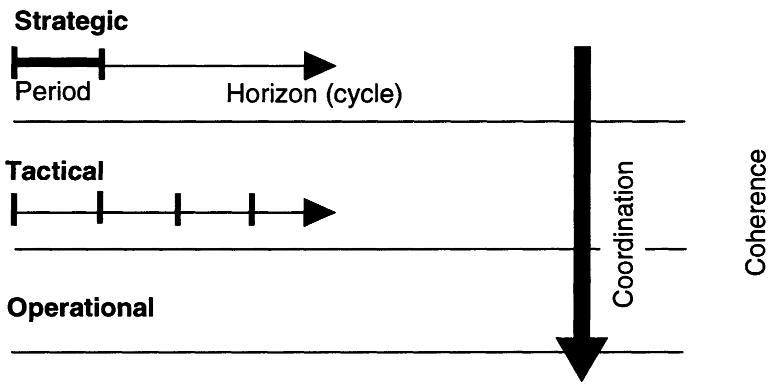

Figure 7.3 Hierarchical aspects: strategic, tactical and operational levels.

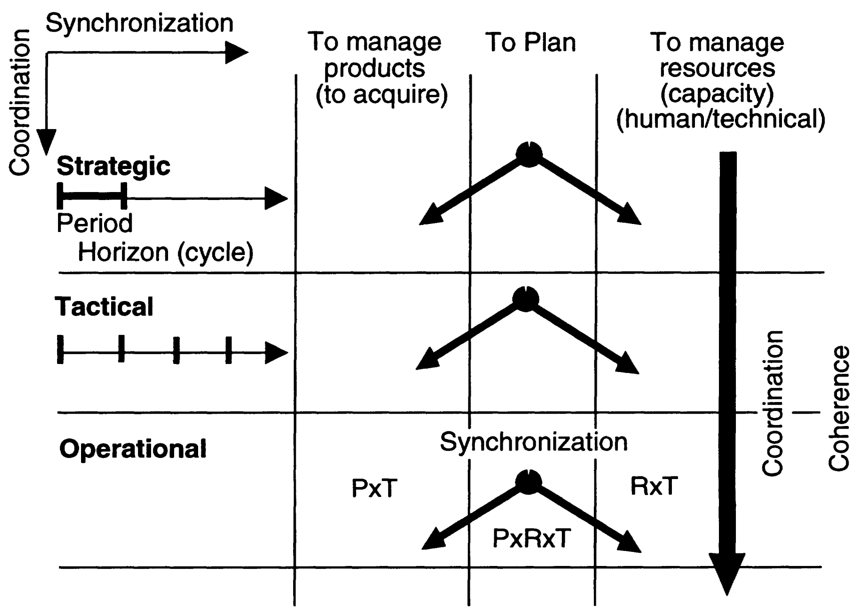

Figure 7.4 Hierarchical and functional aspects.

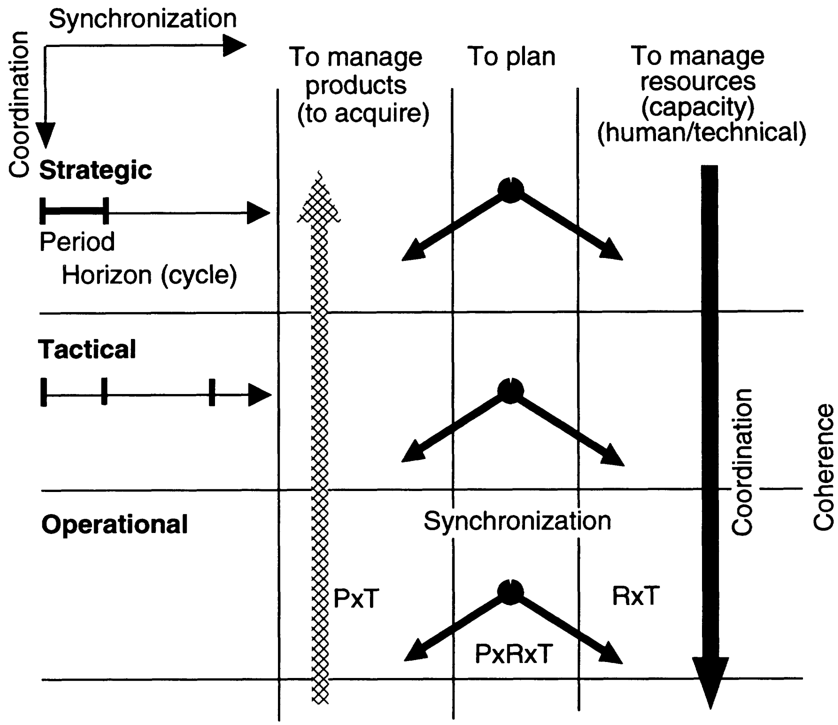

Figure 7.5 Feedback introduction.

characterized by the concept of a time horizon (the time interval during which the result of the decision is relevant) and the concept of a time period (the time interval after which the result of the decision must be reconsidered). This notion is a generalization applied to each of the three classical levels.

This two dimensional decomposition enables the concepts of a decision center to be defined. A decision center contains as a generality all of the decisions made within one function and at one hierarchical level. Fig. 7.6 shows these concepts globally.

The hierarchically organization of the decision system into decision centres which are inter-related makes the information system hierarchically structured as well. Internal information from the physical system and external information from the surrounding environment is filtered and aggregated as required by the hierarchical level having to use it.

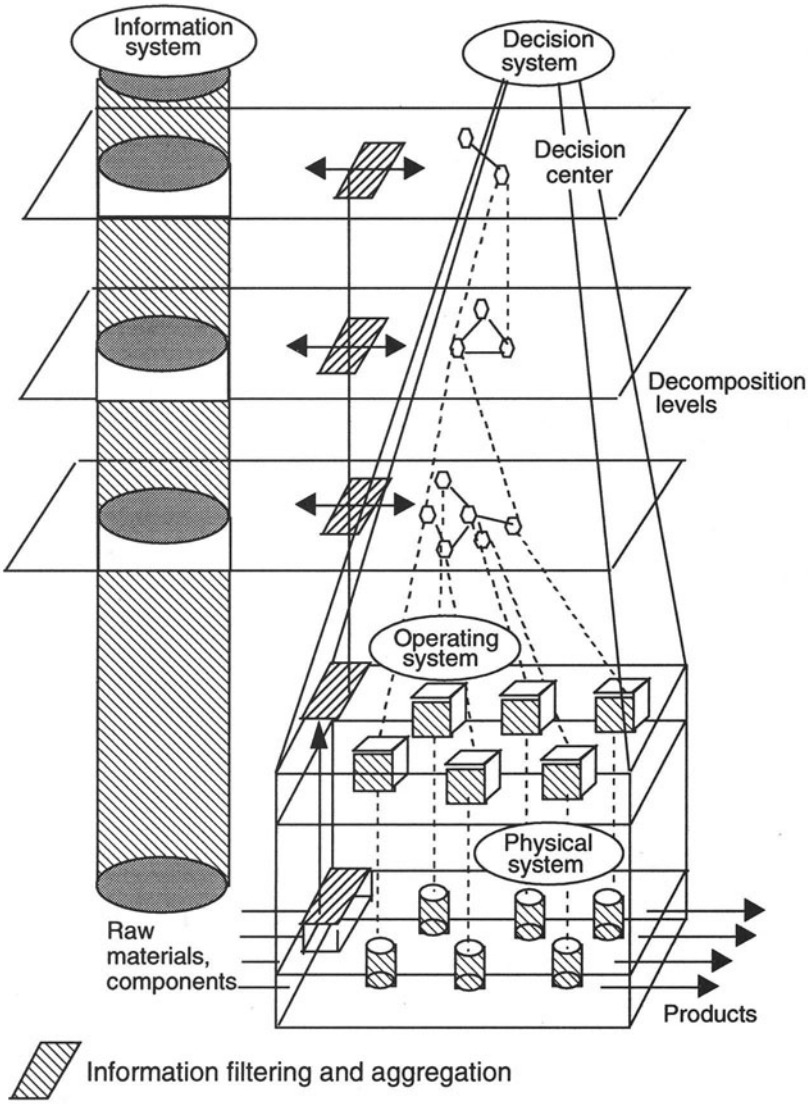

Figure 7.6 The GRAI-GIM global model.

The set consisting of the 'decision system+information system' (the control system) controls the physical system in order to reach the objectives which have been defined for the overall manufacturing system. The expression of this global action of the control system on the physical system must be carried out by each hierarchical level of the structure through the relevant decision making tasks related to the level of decision center considered. It is obvious that the decisions made by a workshop manager within his decision center must operate only on the relevant part of the physical system (here the workshop concerned). The workshop manager has a representation of the physical system completely different from the representation which the production manager has. The expression of this difference is in terms of space (a smaller domain of intervention) and in terms of time. Then for each decision center there is a specific representation of the physical system which is a more or less aggregated view of some activities contained within it.

The operational system shown by Fig. 7.6 is that part of the decision system which is closest to the physical system. The operating system is characterized by its essentially real-time nature. Considering the control system to be hierarchical leads one to consider having a corresponding hierarchical model of the physical system as in Fig. 7.7. Thus, a decision center aims at controlling a part of the physical system. The model which this part of the decision center uses to develop its control operations will come from the

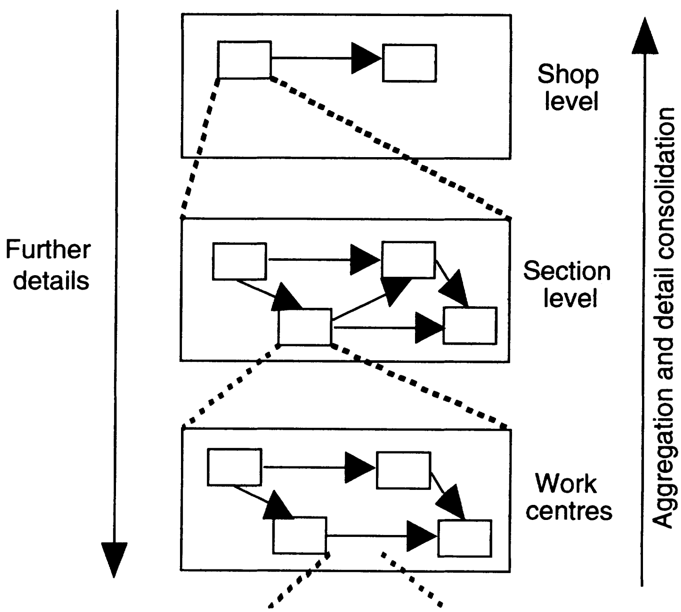

Figure 7.7 Hierarchical model of physical system.

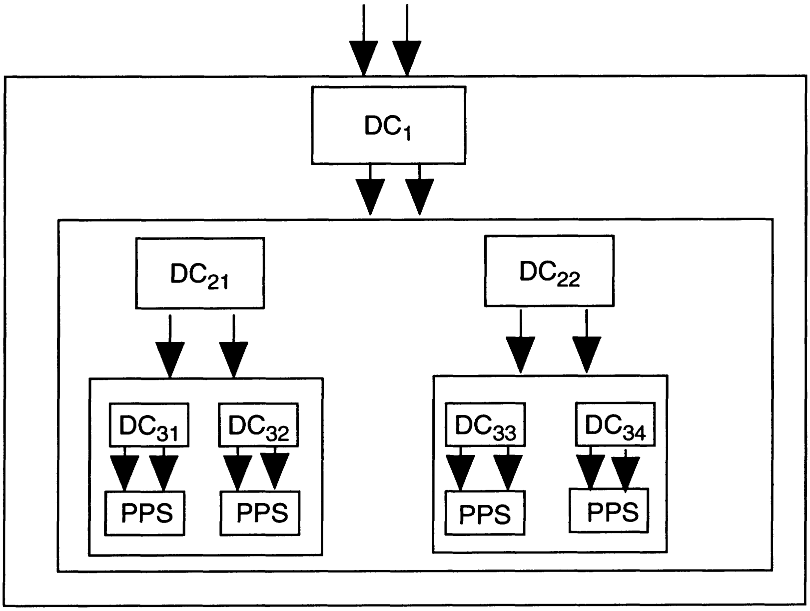

Figure 7.8 Link between hierarchical structure of the control system and hierarchical model of the physical system.

same hierarchical view of the physical system which we have just introduced. This notion leads to a structure where each decision center is dedicated to a part of the physical system as is shown in Fig. 7.8.

To complete this notion of a hierarchical system, we must go back to the concept of aggregation of information. As the level of control which is considered is raised then the information used by this particular level is aggregated or condensed in relation to lower levels. This aggregation makes it possible for this higher level to use information about a larger domain without violating any limit on the quantity of information beyond that with which it is possible to make efficient decisions on all the information available (Fig. 7.9). That is, there is a limit on the volume of information which can be considered at any level.

The domain of decision making is expressed in terms of space (the limit on the size of the part of the physical system controlled by any one decision center – Fig. 7.8) and in terms of time (the notions of horizon and period).

The detailed structure of a decision center will be described overleaf.

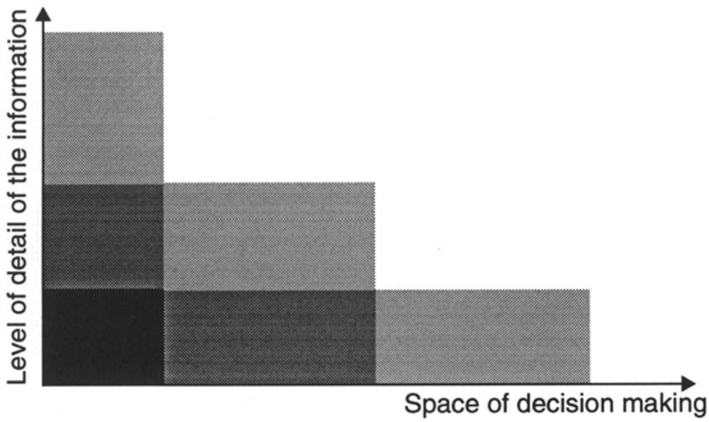

Figure 7.9 Constant volume of absorbable information.

7.2 THE DECISION CENTER MODEL

The reference model of a decision center describes the structure of the decision center itself and the links between it and its neighbors. This model also aims to describe those activities occurring within a decision center.

In order to establish the objectives of the decision center, each activity has its own purpose. These activities are organized in accordance with this purpose. This structural organization is also conditioned by the view of the physical system which the decision center has. The inner structure for these activities, essentially those which are decision oriented, is shown in Fig.7.10. The importance of this model of the physical system and the kind of information necessary for the operation of the decision center must be noticed.

In the global model, the information, decision and physical systems were split up. This division is also relevant within a decision center. Then just as the information and decision systems are connected together within the control system, a decision center is also composed of these same two systems along with a model of its physical system, the true physical system, being external to the others.

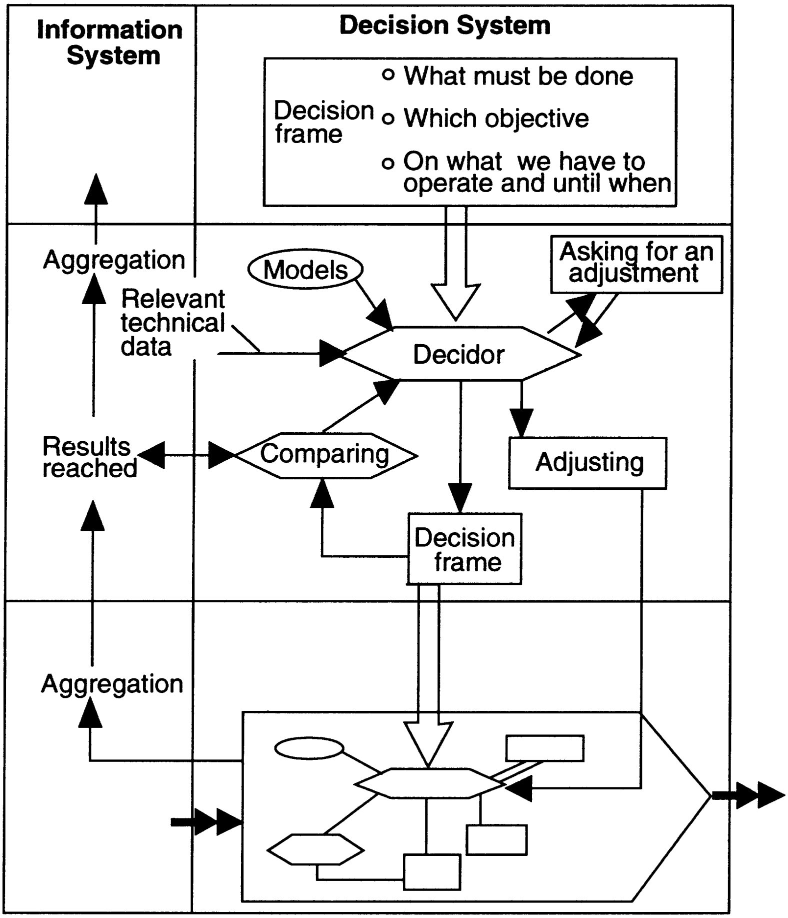

Figure 7.10 The decision centre reference model.

7.3 MODELLING FORMALISMS IN THE GRAI-GIM MODELLING FRAMEWORK

Because of the utilization by GRAI-GIM of several modelling formalisms which exist independently, this section will only present the modelling framework in which these formalisms are used and by which the consistency of the models is assured.

7.4 THE BASIC PRINCIPLE OF THE GRAI-GIM STRUCTURED APPROACH

The aim of the GRAI-GIM structured approach is to support the whole life-cycle of the manufacturing system which is to be designed. Thus, two parts of this life-cycle must be assigned a prominent position:

1. The first part which is user oriented
2. The second part which is technical.

The first part of this approach enables the users to build models establishing their own requirements for the system. The models so obtained must be readily understandable by these same users. These models are expressed according to four views: decisional, informational, physical and functional. The first three of these are related to the decomposition of a manufacturing system as introduced by the GRAI Reference Model as just described. The functional view enables the user to get a simple model of the system expressed in terms of the functions to be carried out.

The second part leads to a technical model of the manufacturing system expressed in terms of organization, information technology and manufacturing technology. Fig. 7.11 shows these two main inputs of the structured approach.

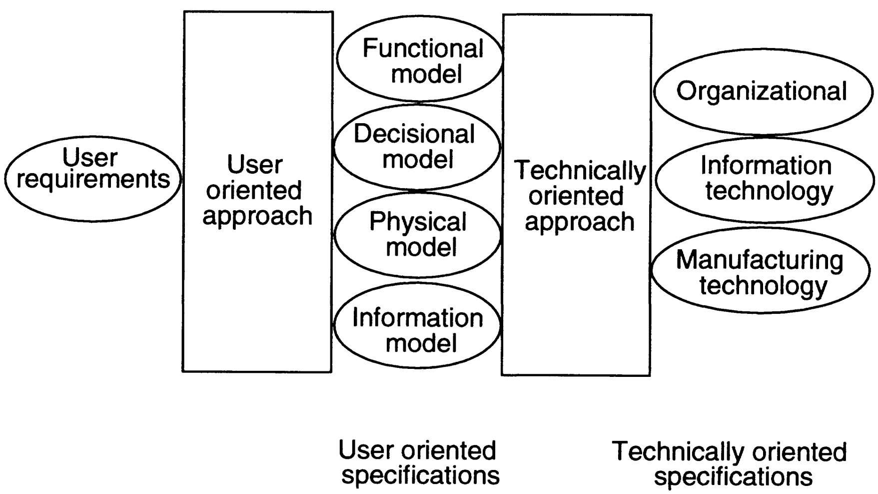

Figure 7.11 User oriented approach and technically oriented approach: the two parts of the global GIM structured approach.

7.5 THE MODELLING FRAMEWORK

Because its high complexity, an initial structuring is needed when designing a CIM system. Various concepts and models need to be defined and incorporated. In order to ensure completeness, consistency and integration between the concepts and the models, we propose to define a modelling framework in which all the models needed for the analysis, design and implementation of CIM systems can be assigned their places (see Fig. 7.12).

The modelling framework has two dimensions: functional decomposition and abstraction levels.

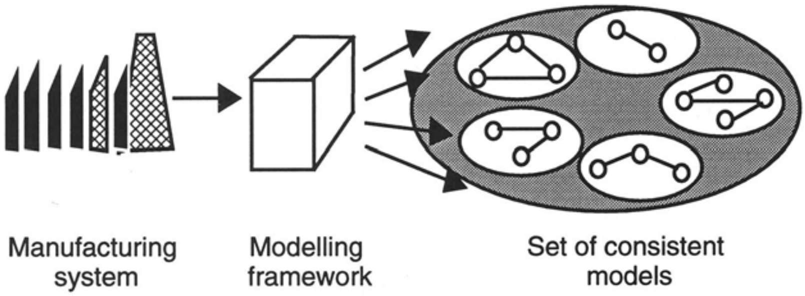

Figure 7.12 The principle of the modelling framework.

7.5.1 Functional decomposition / breakdown

As we have seen any manufacturing system may be split into three systems: the physical system, the decisional system and the informational system (Fig. 7.2). These three systems allow us to obtain three different views. A view can be defined as a selective perception of a manufacturing system which concentrates on some particular aspect and disregards others. To these three views, we add a fourth known as the functional view. The functional view enables one to get a very simple model which shows the main functions of the manufacturing system and the flows (of any nature) moving between these functions. Another advantage of these views is their ability to define exactly the boundary of the study domain.

7.5.2 Abstraction levels

The modelling activity implies a simplification of an otherwise too complex reality. Thus, a model keeps only those concepts and elements which will be necessary at the time of the model's use. The introduction of abstraction levels allows a 'stratified description' in the sense that our model is in fact composed of several, each of which integrates certain specific concepts. Practically, our model uses three abstraction levels:

1. Conceptual level: This is made up without any organizational or technical consideration, it is the steadiest level and aims to ask the question, 'What?'
2. Structural level: It integrates the organizational point of view and aims to ask the questions, 'Who?', 'When?' and 'Where?'
3. Implementable level: It is the more specific level because it integrates the technical constraints of the studied case and aims to ask the question, 'How?'

Finally the GRAI-GIM modelling framework uses the 'modelling domains' shown in Fig. 7.13.

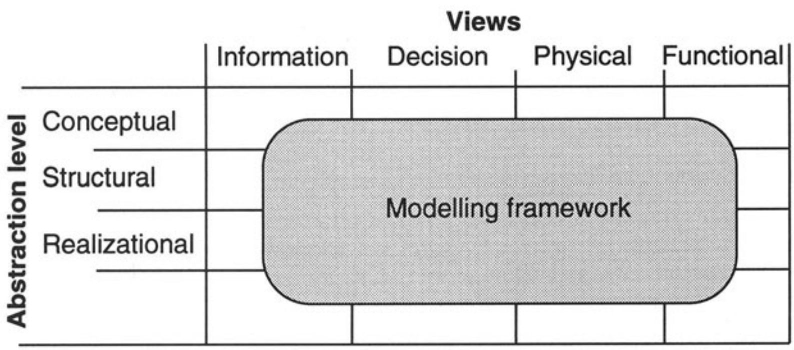

Figure 7.13 The GIM modelling framework.

7.5.3 Modelling framework and structured approach

We now need to adapt the first decomposition which was presented to include the global approach shown in Fig. 7.11 because there is a strong link between the abstraction levels and part of the approach considered (user oriented or technically oriented). In fact, the user oriented approach needs the upper abstraction levels and the technically oriented approach needs the

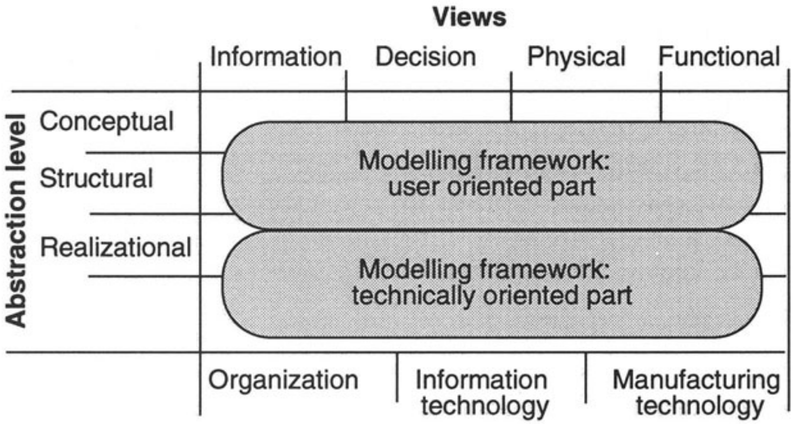

Figure 7.14 The GIM modelling framework: taking into account. the methodology.

lower ones. Fig. 7.14 shows more precisely the modelling framework which must be taken into account in using these two approaches.

7.6 MODELLING FORMALISMS

This discussion will focus on the upper levels of the modelling framework (those which are user oriented). Thus, we will now see the eight corresponding modelling domains (formed by the intersection of a column and a row of the diagram of Fig. 7.14). The formalisms used for each subdomain must be well adapted to the modelling needs of each of them. The needs for each subdomain are as follows:

7.6.1 Conceptual information model

The Conceptual Information Model is a description of all of the stable and 'natural' data of the organization, of their attributes and of the links between them. The formalism used here is the Entity Relationship model.

7.6.2 Structural information model

The Structural Information Model describes the data structure in relation to the distribution of data and the computerized/manual choice. The formalism used here is also the Entity/relationship model.

7.6.3 Conceptual decision model

The Conceptual Decision model is a description of the decision taking structure, the links between decision levels, an analysis of the links between objectives, an analysis of the constraints, and a description of the decision variables involved. The formalism used here is the GRAI grid at the global level and the GRAI net at the detailed level.

7.6.4 Structural decision model

The Structural Decision Model mainly enables the identification of decision makers, and their responsibility and authority. It links decision makers and the decision making process. The formalism used here is the GRAI grid at the global level and the GRAI net at the detailed level.

7.6.5 The Conceptual physical model

The Conceptual Physical Model is a description of the process and the routes taken by the physical flows between operations. The formalism is the actigram IDEF0.

7.6.6 Structural physical model

The Structural Physical Model gives information about time, work centres and operators. It includes the elements about linking and synchronization and indicates who does what. The formalism is the actigram IDEF0.

Fig. 7.15 shows the user oriented part of the GRAI-GIM reference framework with the modelling formalisms used.

7.7 VALIDATION BETWEEN MODELS

Validation between models is one of the foundations of our approach. We began indeed by applying an analytic approach (decomposition) to the studied system. We went from an overall view of the system/real object to these

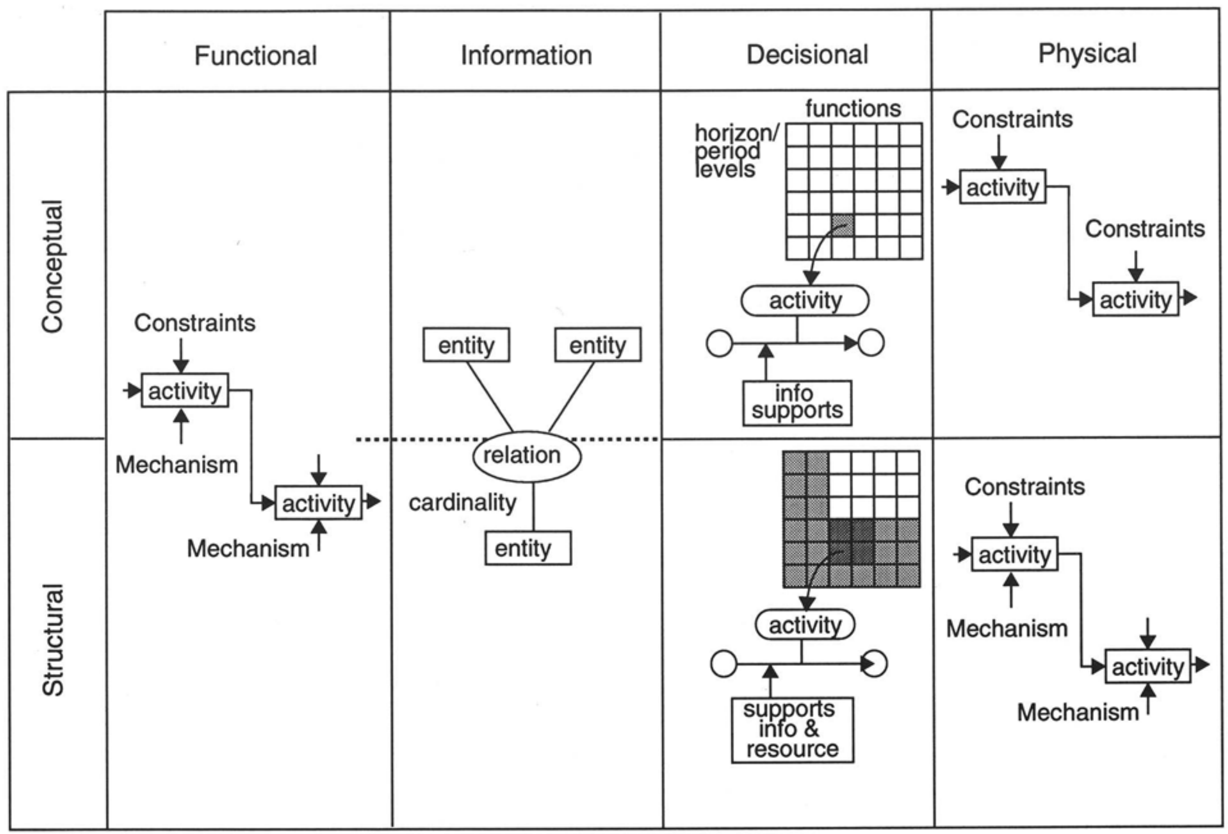

Figure 7.15 GIM reference framework with the modelling formalisms used.

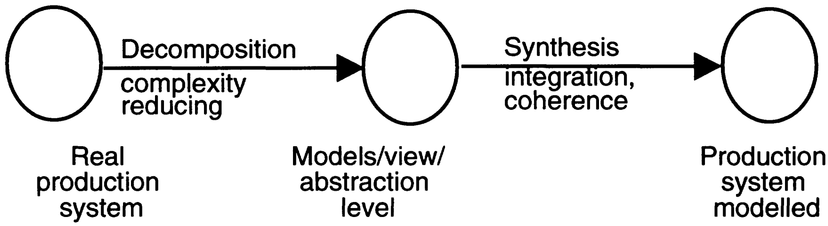

Figure 7.16 Decomposition / synthesis type cycle supporting the GIM approach.

separated models according to the views and abstraction levels described. The complete model will be obtained only by applying a set of validation rules between each set of the model. The aim of the validation is to impose a global coherence onto the study. The structured approach is supported by the application of a decomposition/synthesis type cycle (Fig. 7.16).

Validation between models can be achieved only if we can find an element present in all the partial models. As shown on Fig. 7.17 the subsystems are connected through data:

1. The decision subsystem makes decisions and processes data
2. The physical subsystem aims to process physical flows but is the source of process data for the information and decision subsystems.

Data are the only means of communication between subsystems, and they are the validating elements required. Thus, the basic point of the validation between models will be realized by imposing data coherence. Fig. 7.18 shows an example of validation between the Conceptual Decision Model and the Physical Conceptual Model through data.

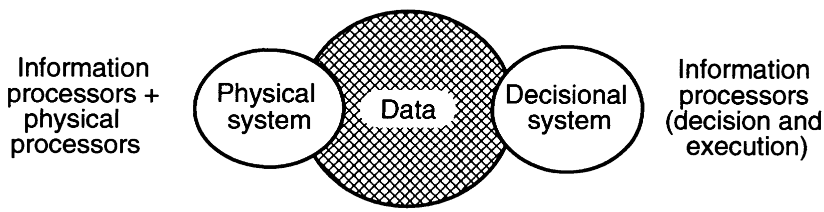

Figure 7.17 Data as vector of communication.

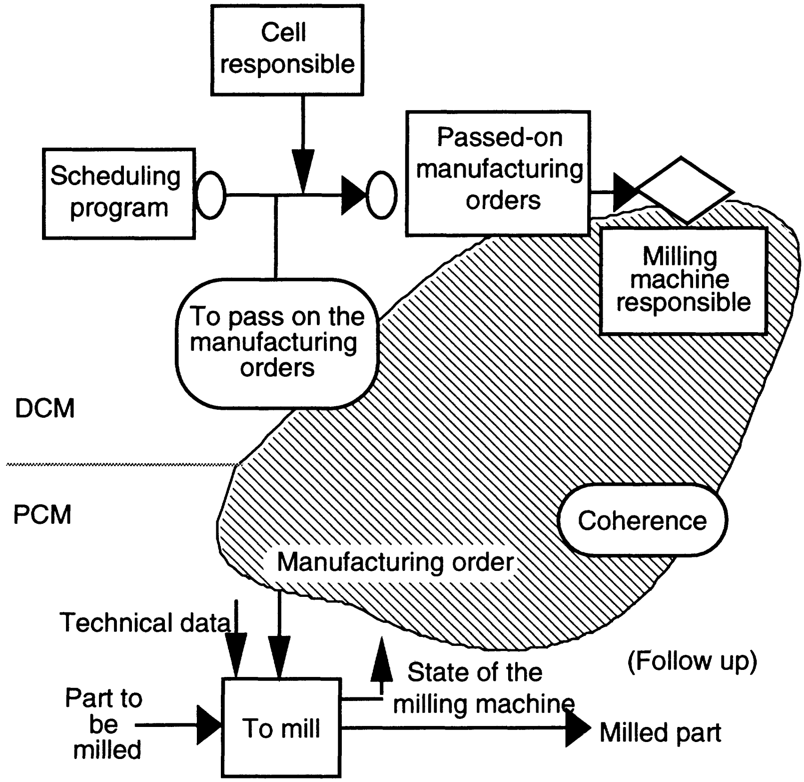

Figure 7.18 Example of validation between conceptual decision model and physical conceptual model through data.

7.8 GRAI-GIM STRUCTURED APPROACH

According to the user requirements for the future system, the goal of GRAI-GIM is to provide specifications for the system in terms of organization, information technology and manufacturing, which will allow the user to build this new system.

The structured approach of this method has four major phases: initialization, analysis, design and implementation. We will focus mainly on the three first phases and will provide only some 'orientations' for the implementation phase. See Fig. 7.19.

One of the main advantages of this method is to split up the design phase into two subphases: that for the user oriented design and that for the

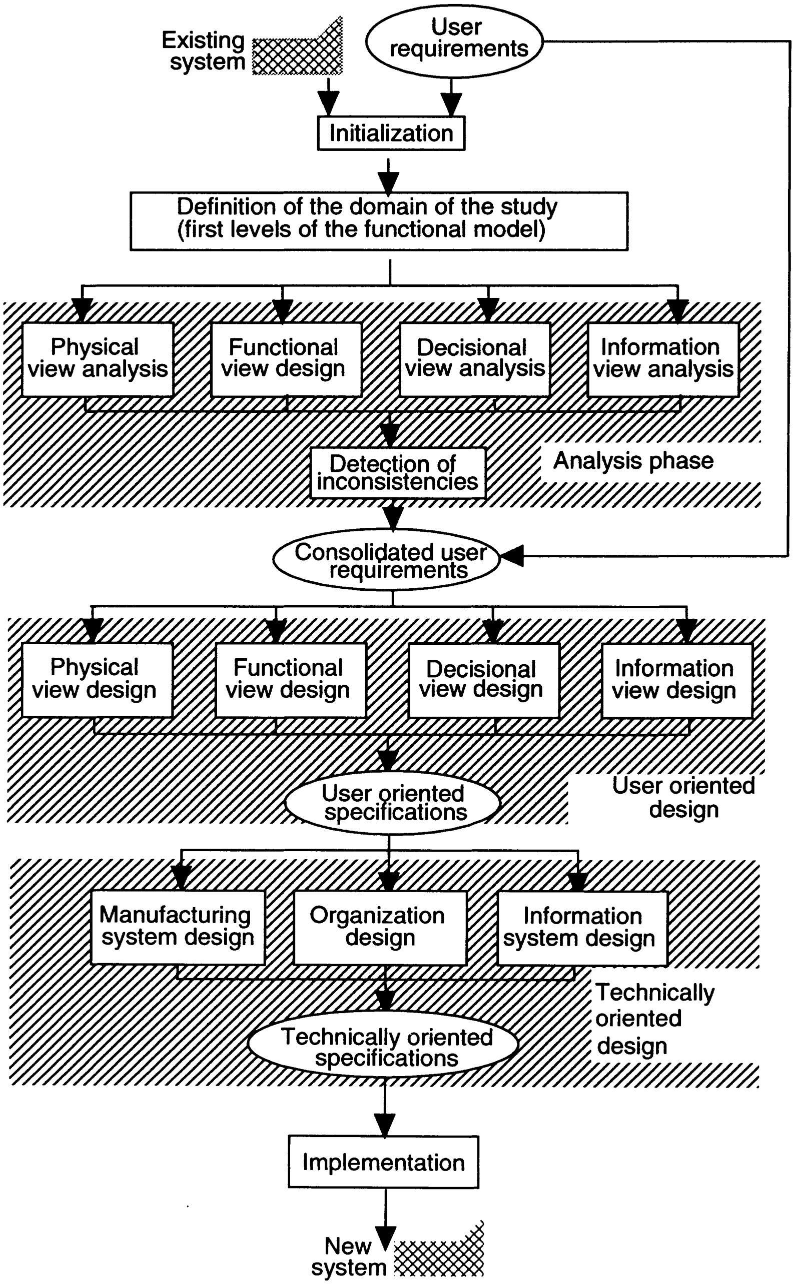

Figure 7.19 GRAI-GM structured approach.

technically oriented design. We consider that the techniques used to build new manufacturing systems are currently very difficult for the users of the future system to understand. This is particularly true for the information technology domain. In addition, because of the amount of investment necessary to build a new manufacturing system, we need to be sure that the design of the new system reaches the objectives defined in the user's requirement. The design of the new system must thus be validated by the user before the start of any developments or implementations.

Because of these remarks, we have split up the design phase into two subphases: the user oriented design which provides a set of user oriented specifications understandable by the users and the technically oriented design which provides the technical specifications necessary for the development and the implementation of the future system.

The users will then validate the user oriented specifications to be sure that the design provides the efficient solutions to their requirements.

7.9 INITIALIZATION PHASE

This phase includes eight main steps:
1. Overall definition of the company
2. Presentation of the method to the company managers
3. Definition of the domain of the study
4. Diagnosis
5. Initialization milestone
6. Definition of the people involved in the study
7. Training of the participants
8. Planning and resources for the next phase.

7.10 ANALYSIS PHASE

This step permits us to define the characteristics required of the current system. It is also necessary to know the interfaces between the studied domain and other functions like Marketing or the Financial Department for example.

As it has been defined in the GRAI-GIM modelling framework, the analysis concerns mainly the modelling of the four views: functional, decisional, informational and physical views. To model these views, we will use the modelling tools defined previously for the design of the GRAI-GIM architecture (IDEF0, GRAI grid and nets, and the Entity Relationship tools).

7.11 DESIGN PHASE

When the analysis phase has been approved as noted above, it is necessary, before starting the technical design, to redefine clearly the various inputs which will be the basis for this phase. We have formalized the existing system, we have detected the inconsistencies of this system and we know the objectives of the company. The design phase is split up into two main steps. A first step as noted is more user oriented where the users are involved during the design of the four views and must validate the results to allow the study to continue. The result of this first step is the user oriented specifications. Working according to these specifications, experts in manufacturing, organization and information technology are then put in charge of performing the technically oriented design step. The result of this step will be the technical specifications of the future system which will allow the user to choose system components (machines, computers, software packages, databases, human resources, etc) from the market or to develop them themselves, and then implement the new system.

7.12 IMPLEMENTATION PHASE

The implementation phase can itself be split up into three tasks: the installation of the new resources and the training of the users, the preparation for the starting up of the new system and finally, the complete operation of the new system. The problem in this phase is to ensure a good transition between the current and the new system with a minimum of impact on the production operating.

7.13 A SUMMARY OF HOW TO USE GRAI-GIM

The objectives of GRAI-GIM are to develop the specifications for a CIM system in order to:

1. Design the specific architecture of the CIM system being studied with all the components and the links between them, and
2. To give the specifications for all these components in order to select them from those already on the market, or to define the requirement for the development of these components.

If we consider the life-cycle of the manufacturing system, GRAI-GIM concerns itself only with the first phase: Analysis/Design, it does not treat

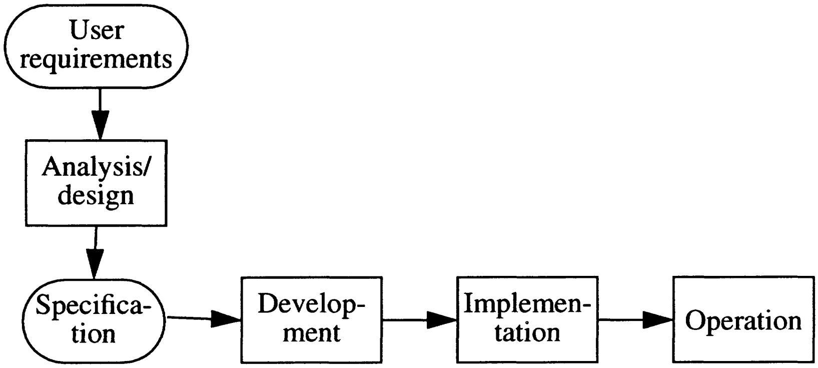

Figure 7.20 Life-cycle of a manufacturing system.

Development. GRAI-GIM is an input for this second phase as shown in Fig.7.20.

GRAI-GIM could be helpful in the Implementation Phase or in the Operating Phase as a reference, as a guide, or a training tool.

The difficulties involved in producing these specifications are the consequences of a double set of constraints:

1. The specifications for the proposed solutions must be validated by the users
2. The specifications for the proposed solutions must be understood on a technical point of view by the potential vendors of the necessary components.

To answer to this dual problem, GRAI-GIM proposes to develop two kinds of specifications:

1. User oriented
2. Technically oriented (see Fig. 7.11).

For the user oriented specifications, the GRAI Model is used with the three subsystems: decisional, informational and physical plus the functional view. We describe these specifications at each of the two levels:

1. Conceptual: in term of concepts,
2. Structural: in term of structure.

Taking the model for the Physical subsystem for example, at the conceptual level, one defines the basic manufacturing operations and the global capacity needed for each type of manufacturing operation (turning, drilling, milling, etc.). The physical model at the structural level evaluates the number of machines needed, and the placement of these machines into cells or shops. Various criteria must be considered for this placement, such as economic criteria, safety criteria and flexibility criteria. For example, to structure three manufacturing operations (turning, drilling and milling) into a cell, one can use three individual machines or one machining center capable of performing all the three kinds of operations. The first structure is safe and allows one to reach to a machine breakdown, the second structure is flexible but is less safe.

For technically oriented specifications we have analyzed the potential groupings of solutions and have classified these solutions into three domains:

1. Information Technology: hardware, software, packages, (CAD systems, Computer Aided Production Management, Computer Aided Maintenance, Computer Aided Process Planning....) Local Area Networks, Data Bases Management Systems, Controls for NC machine tools, Robots, transport systems and warehouses.
2. Manufacturing Technology: all equipments concerning Machine Tools, Specialized Machines, Warehouses, Transport systems, Robots, etc., as well as Human Operators.
3. Organization: Concerned mainly with how the management of the manufacturing system is organized, the principles of management, the organization into workshop, cell....

The technically oriented specifications are involved with two levels: structural and implementable. At the structural level we give the generic requirements in order to choose the solution. At the implementable level, we choose an effective solution available on the market. At this last stage, we may find that the solution does not exist on the market and a new device must be developed. The specifications are the starting point for this development.

7.14 CONCLUSION

The GRAI-GIM method is developed more for the user oriented design than for the technically oriented design. The design of the GRAI-GIM method is an on - going process and the next development will allow an improvement of the technically oriented design phase. Besides, because of the amount of work necessary to model all of the necessary views used during the analysis and the design phase, the use of a computer tool support is absolutely necessary. All the supports allowing the design to be concentrated on added value activities must be provided. A computer tool support will allow one to facilitate the modelling of the views, the coherence checking between the models, the detection of inconsistencies, the use of reference models during the design phase and the production of documents.

7.15 REFERENCES

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