APPLICATION OF MACROERGONOMICS PRINCIPLES IN THE IMPLEMENTATION OF COMPUTER INTEGRATED MANUFACTURING SYSTEMS

Leonardo Rivera C.

Full-time Professor, Universidad Icesi
Contacto: leonardo@icesi.edu.co

Abstract

Many implementations of Computer Integrated Manufacturing Systems (CIMS) have been plagued by failures. Some of the causes of these failures have been identified as the neglect of recognizing and addressing the organizational and human dimensions of a large-scale technological change, as a CIMS implementation is. In this paper, MacroErgonomics Analysis and Design (MEAD) is used as a framework to implicitly recognize these factors and address them from the design phases of the new work system.

Keywords: Computer Integrated Manufacturing, Macroergonomics, Sociotechnical Systems.

Resumen

Muchas implementaciones de Sistemas de Manufactura Integrada por Computador (CIMS, por sus siglas en Inglés) han estado plagadas de fallas e imprevistos. En algunos casos se han identificado como causa raíz de estas fallas el desconocimiento y la no consideración de las dimensiones humanas y organizacionales de un cambio técnico de gran escala. En este artículo se utilice el Análisis y Diseño Macroergonómico (MEAD, su sigla en Inglés) como un marco de referencia para reconocer de manera implícita estos factores y considerarlos desde las fases de diseño de un nuevo sistema de trabajo.

Palabras Clave: Manufactura Integrada por Computador, Macroergonomía, Sistemas Sociotécnicos.

1. Introduction

Computer Integrated Manufacturing Systems (CIMS) are an area of great development in recent years, especially since the middle of the 1980's. They have been widely applied in a diversity of manufacturing organizations that feel the need for modernization and a range of competitive pressures coming from different sources. According to Mital and Anand (1992), cited in Mital (1997), some of this pressures are:

- (The) need to enhance the standard of living through the creation of national wealth;
- (The) loss of global competitiveness, and prestige, due to the inability to produce high-quality products;
- (The) fear of intellectual stagnation;
- the loss of creative edge;
- the need to respond to market demands quickly;
- the need to prepare for market and technological changes that are occurring more frequently than ever.

It was frequently advocated, especially in the initial stages of CIMS, that extensive automation and mechanization would lead to the solution of many of those problems. Terms like *"lights-out-factories"* were coined to signal the ideal of having automatic factories that would be able to run without the need for human intervention, therefore making completely unnecessary the use of lighting inside the manufacturing plant.

> *"A 1992 Industry Week survey of executives and managers in in US manufacturing industries, approximately 81% of the respondents regarded CIM as essential or very important as a competitive weapon. Approximately 66% felt that CIM was an important cornerstone for world-class manufacturing"*. (Mcgaughey and Roach, 1997).

However, in CIMS implementations, as with any technological large scale change, there have been success stories but also countless tales of failure and disgrace, even taking companies down the road of bankruptcy. Some believe that the failure rate for technologies such as CIM may be as high as 50% to 75% for US firms (Cleland *et al*. 1995, Saraph and Sebastian 1992).

Some authors have analyzed the reasons for failure in CIMS implementations through surveys of practitioners. In particular, Mcgaughey and Roach (1997) sent 428 surveys to professionals involved in the implementation of CIMS in factories and obtained 101 responses, in which the eight (out of 21) most significant factors (obstacles to CIMS success) were, in descending order of importance:

- Inadequate leadership
- Lack of top management support and commitment
- Inadequate planning
- Inadequate analysis of user needs
- Inadequate funding
- Inadequate system design
- Lack of people with technical expertise
- Corporate culture not right for CIM

It is interesting that these factors have nothing to do with the technology itself, but with the way in which humans organize the company, make the relevant decisions and go about the implementation of the system.

Obviously, it would be interesting to discuss ways in which there pitfalls can be avoided, improving the planning and design stages of the implementation process to encompass all the elements of the manufacturing enterprise. CIMS implementations are not only a matter of technology, they are Large Scale Changes that affect all the company and its immediate environment.

> *"…Restructuring measures are crucial which from a work-psychological point of view are designed in line with the following principles:*
> - *Organizational design prior to automation*
> - *Education and training as a strategic investment*
> - *Functional integration*
> - *Local self-regulation.*
>
> *Such changes are no doubt time-consuming, but eventually less costly and make a considerable contribution to humane working conditions and economic efficiency"*. (Ulich, 1993).

In this paper, an approach called Macroergonomics (ME), based in the Theory of Sociotechnical Systems will be applied to CIMS implementation in order to address the change process with a systemic view.

2. Background: Macroergonomics

Macroergonomics is a sociotechnical systems approach to work system design (Hendrick and Kleiner, 2001). It is, therefore, the application of the SocioTechnical Systems Theory (STS) to the configuration of the enterprise and the interaction of the components in such a system.

2.1. Sociotechnical Systems

The Sociotechnical Systems model was developed in the Tavistock Institute of Human Relations in the United Kingdom, during the late 1940s and 1950s. The leaders of these efforts were F. Emery, E. Trist and K Baumforth. Later these models have been confirmed in different schools and experiences in different regions of the world.

A turning point of the development of STS were the experiments conducted in a coal mine in Wales (Trist and Baumforth, 1951). The traditional mining systems were basically manual, with the workers organized in small autonomous teams. Each worker performed a variety of tasks, and they were cross trained and capable of taking somebody else's position.

These systems were deemed unproductive, and a new and more technologically efficient system was implemented. This new system, called *longwall*, changed the way people worked. Now, groups of 10 to 20 workers were required at a time, and each of them had to specialize in narrow, well-defined repetitive tasks. Also, a high level of interdependence between the work of the three shifts caused that problems occurred in one shift were carried to the next one, diminishing the possibility to complete the assigned work.

When the second system was implemented it was plagued with low throughput, high absenteeism and rivalry between workgroups. The reasons for these problems were investigated and some of the findings were:

- In the old technology, each group had considerable autonomy.
- In the new system, the opportunity for social interaction was greatly reduced.
- In the new system, workers could not achieve the satisfaction of work completion (the tasks were carried to the next shift sometimes).
- In the new system, workers felt trapped in little tasks, because job rotation was not done and they were not cross-trained.

According to these findings, for new mine implementations, the work system was redesigned with what was then called a *composite* method, which combined the social characteristics of the old system with the technological advantages of the new one. Production was then higher than in the old system or in the *longwall* system.

> *"The key is to select a work system design that is compatible with the characteristics of the people who will perform the tasks and the relevant external environment, and then employ the technology in a manner that achieves congruence with it"*. (Hendrick and Kleiner, 2001).

From these initial experiments and the subsequent research and implementation processes, the principles of sociotechnical systems were derived. A brief presentation of these principles follows (Oborski, 2003):

1. *Minimum Critical Specification:* An employee must given the minimum amount of specifications over the task to ensure that it will be done correctly.
2. *Variance Control:* Problems must be corrected as close to the point of origin as possible and preferably by the group that caused them.
3. *Multi-Skilling:* Give individuals a range of tasks including some routine and some challenging.
4. *Boundary management:* Identify boundaries between groups and functions. Ensure that the people on them have the information necessary to pass the product smoothly to its next transformation stage.
5. *Information flow:* The information system should be designed so the information goes directly to the place where action is to be taken or to the source that originated it.
6. *Designee and human values:* It recognizes the need to be able to learn on the job, the need for an area of decision making, the need to relate work to social life, the need to feel the job leads to a desirable future.
7. *Incompletion:* The need to recognize that design is an ongoing and iterative process.

2.2. Macroergonomics

In 1978 the Human Factors and Ergonomics Society commissioned a study on the future of the field. Hal Hendrick was appointed head of the Committee. Their key findings lead them to propose that there was a need to integrate ergonomics with

Organizational Design and Management, with Macroergonomics in charge of studying the design and improvement of work systems.

Hendrick proposed that the profession of Ergonomics is in charge of analyzing and designing the interfaces between human and system, and from the different subdivisions of these interfaces the common specialties of Ergonomics can be derived (Hendrick, 1998 cited in Hendrick and Kleiner, 2001):

- Human-*machine* interface technology: Hardware Ergonomics
- Human-*environment* interface technology: Environmental Ergonomics
- Human-*software* interface technology: Cognitive Ergonomics
- Human-*Job* interface technology: Work Design Ergonomics
- Human-*organization* interface technology: **Macroergonomics**.

The Macroergonomic model of the organization is based in the recognition that the it can not be successfully analyzed and improved without taking into account its different subsystems and its interactions, as well as the environment that surrounds it (which is often the most important component). The summarized model can be observed in **Figure 1**.

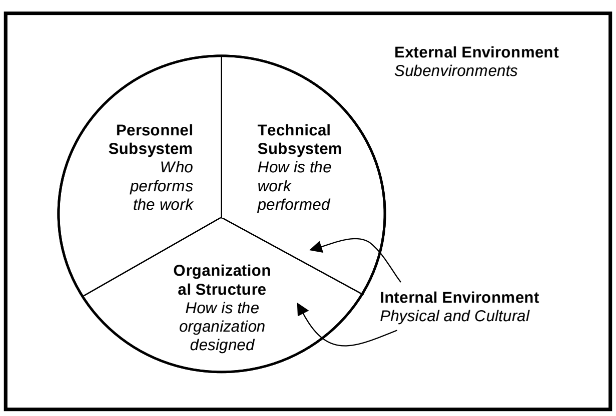


Figure 1: Macroergonomics model of the organization.

In this model, four main subsystems can be differentiated: Environment, Technical Subsystem, Organizational Structure and Personnel Subsystem. The model is quite simple, yet it emphasizes in the relationships and interconnectedness of its components.

Based on the principles of Sociotechnical Systems, Macroergonomics propose that an effective approach to work system design needs to have the following characteristics:

- *Joint Design:* Both the human and technological subsystems must be designed concurrently, with a *human-centered focus*. This design should allow for extensive employee participation.
- *Humanized Task Approach:* A traditional pitfall (that must be avoided) has been the allocation of tasks to computers or machines because *they can do it*, and the leftover tasks are assigned to the humans. Instead, the approach taken must result in tasks that make full use of human skills and compensate for human limitations, making the job fulfilling. The leftover functions are left for computers and machines. (Bailey, 1989).
- *Consider the organization's sociotechnical characteristics:* The approach should consider explicitly these characteristics and incorporate them into the work system design process.

The application of these principles is done through the MacroErgonomic Analysis and Design (MEAD) (Hendrick and Kleiner, 2001). MEAD is a methodology constructed to plan and implement the design of a work system, and its basic structure is presented in **Figure 2**.

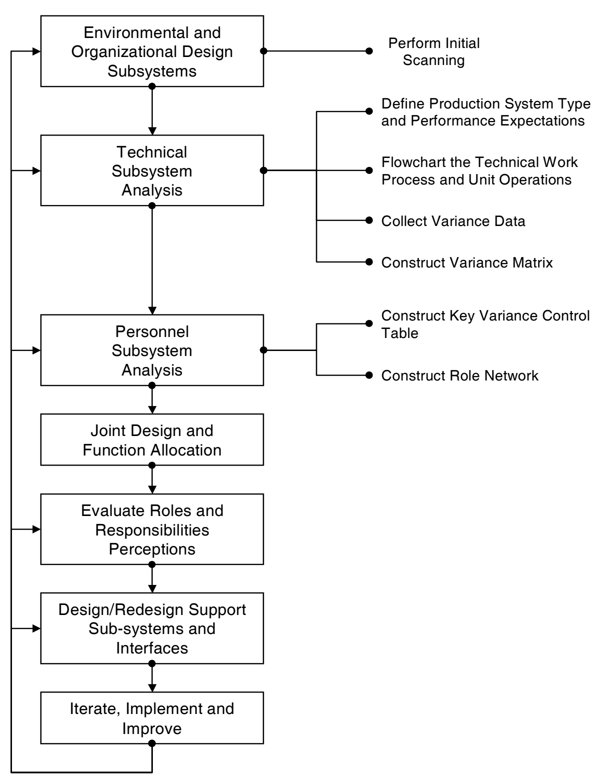


Figure 2: MEAD (Adapted from Hendrick and Kleiner, 2001)

In the next section this MEAD model will be used to propose a general plan of implementation for CIMS, adapting and specifying its different stages to the situation of a company considering it.

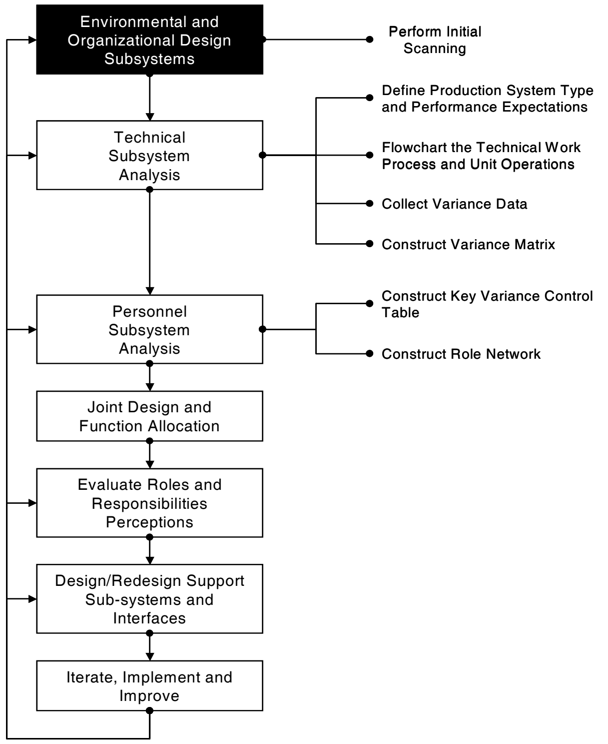
3. Application of Mead to Cims

The steps of MEAD will be followed in order, making the necessary clarifications along the way.

3.1. Environmental and Organizational Design Scanning

3.1.1. Perform Environmental Scan

First, it is necessary to define the organization's boundaries. This encompasses the task of finding the scope and reach of the organization, and also can help to define the *core competencies* of the organization.



Next, the external environment needs to be understood. It is conformed by *subenvironments*, which represent the different actors in the overall environment. Some subenvironments of interest are:

- Government
- Public opinion
- Consumers
- Companies in the same industrial sector
- Shareholders

These subenvironments have demands and expectations over the organization, and also present trends of change and evolution over time. It is important to understand them to decide on a strategic course that is consistent with what the environment presents and enhances the probabilities of success.

At this point, the company needs to decide if the implementation of CIMS is relevant and adequate for them. This implementation implies a large scale organizational change, and a big commitment of resources, therefore the company needs to realize if it is the right course of action and reflect it on its Mission, Vision and Principles, which will be discussed in the next section.

3.1.2. Perform Mission, Vision and Principles Analysis

A Mission describes the company's main business, products and services. A Vision states what the company wants to be, usually projected into the future. Principles are a set of values and standards that the company holds dear and must permeate into every decision and activity of the company.

The company that is interested in implementing CIMS must first decide if CIMS support their Mission, Vision and Principles (MVP). For example, it would not be congruent if a company professes that they want to give personalized attention to every customer and they implement a fully-automated menu-based telephone response system to deal with their complaints without the need for human contact. At this point, if there is a discrepancy between what the automated operations will bring to the company and its MVP, there are two alternatives:

1. Change the operational design of the system so it is consistent with its MVP. This course of action should be taken when the MVP is deemed critical for the success of the company.
2. Change the MVP. This should be done when the old MVP becomes obsolete or misaligned with the needs of the market and the company's environment. In this case, a reexamination of the whole strategic purpose of the company is in order.

3.1.3. Perform System Scan

This will allow the company to define itself as a system, examining the different components of the systems view. Simple models like a Systems Flow Diagram (**Figure 3**) help to describe the organization in simple terms.

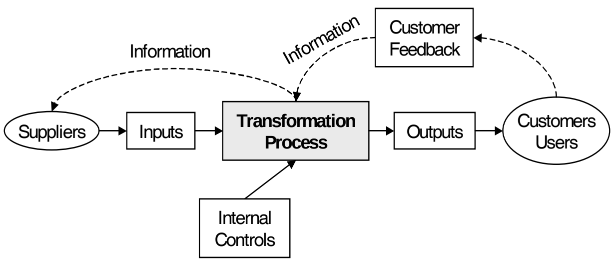


Figure 3: Systems Flow Diagram (Deming Diagram)

A CIMS implementation will undoubtedly alter the way the company conducts the transformation process, but also can change profoundly the way the company interacts with customers and suppliers. In general, changes in the communication means and protocols must be designed in agreement with the suppliers (which the company needs in compliance and functioning adequately) and the customers (which must find the new interactions satisfactory and adequate).

3.1.4. Specify Initial Organizational Design Dimensions

In organizational design, it is recognized that there exist several dimensions that have to be considered when choosing an organizational structure:

- *Complexity:*
    - o *Differentiation:* Implies the degree of specialization and separation in organizational units or levels.
    - o *Integration:* Mechanisms (formal and informal) that exist to integrate the parts of the organization for communication, coordination and control.
- *Formalization:* It shows the degree to which jobs are standardized in the organization.
- *Centralization:* It is the degree to which authority and decision making abilities are concentrated on a few individuals at top of the organizational structure.

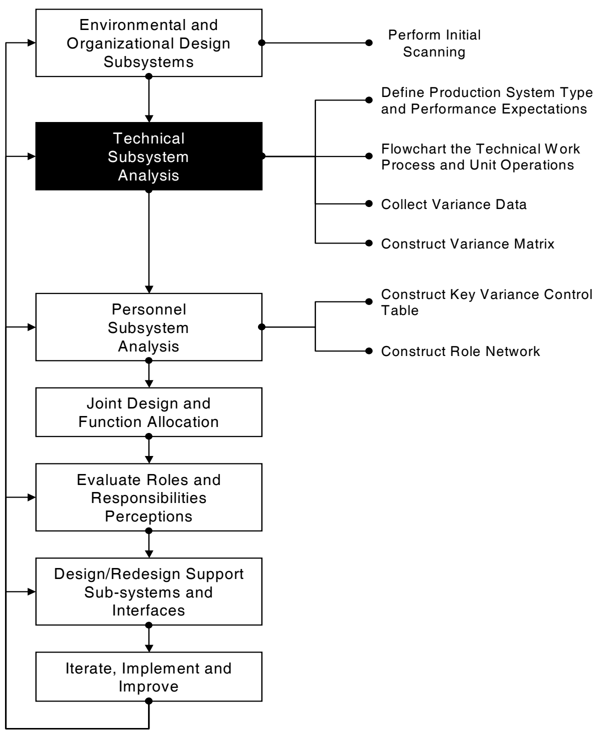
Thinking of these dimensions specifically in terms of a CIMS implementation, some important aspects need to be discussed:

- *Complexity:* Related to CIMS, the complexity of the new system will create the need for new specific knowledge and expertise, which will probably increase the degree of differentiation. Also, the underlying enterprise-wide information systems implied in CIMS implementations (their local flavor of ERP systems) should be used as tools to enhance *integration*. Referring also to the sociotechnical principle of *Information Flow*, information systems need to be used to provide everybody in the company with the information they need presented in the way that is most efficient and simple for them. A traditional problem of information systems is that they present a clutter of data that can make users feel overwhelmed, so this is where the design of human-software interfaces becomes critical in terms of ergonomics and usability.
- *Formalization:* The need to specify parameters and roles in a CIMS will increase the degree of formalization of jobs. This creates a paradox, because increased formalization usually means increased rigidity, which no company desires. If an information system is used, users should be trained not only to use their screens and modules, but also to understand their role as a part of the whole system and to be able to fulfill different roles. This relates to the sociotechnical principles of *Information Flow* and *Designee and Human Values*, and can be used effectively to increase personnel flexibility.
- *Centralization:* To keep a company flexible, provisions should be made to make decisions and adjustments as close to the source of the problems as possible (sociotechnical principle of *Variance Control*). Therefore, the information needs to be centralized to guarantee its consistency and integrity, but it must be used in a highly decentralized manner.

In relation to organizational structure, there are several types of structures commonly used, namely Functional organizations, Product-oriented organizations and Matricial organizations. Their characteristics will not be discussed here. However, organization of production operations in CIMS environments with FMS implementations will naturally tend to be product-oriented, given the use of Group Technology to form part families and assign them to specific FMS cells. Also, given the decentralized nature of decision making and the availability of information enterprise-wide, the degree of vertical differentiation should tend to be lower than before. Organizational structure will not be discussed in detail here; the reader is referred to different resources available in the literature (Robbins, 1983).

3.2. Technical Subsystem Analysis

3.2.1. Production System Type and Performance Expectations



3.2.1.1. Define Production System Type

Perrow (1967), cited in Hendrick and Kleiner (2001), proposes a framework to characterize the main types of production systems, based on the *task variability* (the proportion of the time the task conforms to the predetermined standards) and the *task analyzability* (how easy it is to analyze the exceptions to the standards mentioned above). Based on these two parameters, Perrow presents a matrix with four possible combinations of task analyzability and variability. The matrix is depicted in **Figure 4.**

Task Analyzability	Task Variability: *Routine with few exceptions*	Task Variability: *High Variety with many exceptions*
Well-defined and analyzable	Routine	Engineering
Ill-defined and analyzable	Craft	Nonroutine

Figure 4: Perrow's Classification Scheme

Traditional CIMS (through FMS) have been used in discrete production environments with a medium volume of production and a medium volume of product variety. Recently also assembly operations and other production processes have been incorporated. In Perrow's scheme, a normal run of production with established products would fall into the Routine category, and the process of design and launch of new parts would fall into the Engineering category. According to the prescriptions of Macroergonomics, Routine production systems can be product-oriented and have up to four levels of vertical differentiation. Engineering production systems must have high horizontal differentiation (many different types of knowledge are required) and low formalization. This means that the design process must be very flexible, give space for informality and decentralization, to enable creativity and participatory design, involving participants from different areas of the organization as well as customers and suppliers.

3.2.1.2. Define Performance Expectations

Sink and Tuttle (1989) propose a model to standardize performance measurement over the different components of Deming's System Flow Diagram (**Figure 5**). In this model, performance is checked at different points. In the lower part of the graph, performance is measured between inputs and outputs (productivity), at the input level (efficiency), at the output level (effectiveness), between inputs and the customers (profitability) and in the transformation process itself (innovation and Quality of Work Life).

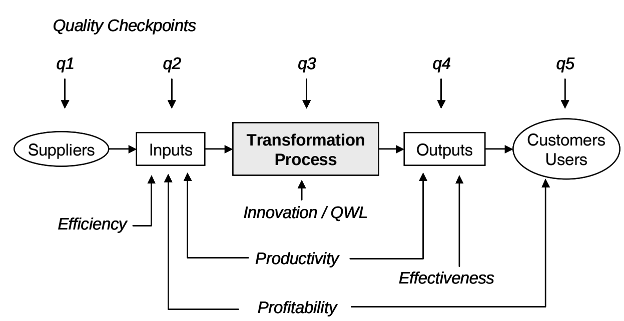


Figure 5: Sink and Tuttle's performance measurement model

In the upper part of the model, quality is checked in every one of the components of the system.

Related to what is expected in a company intending to implement CIMS; improvements would be expected in most of the performance measures. Specifically, CIMS implementation would be justifiable if the improvements happened from the transformation process to the right of the diagram, meaning improvement of Profitability, Productivity, Effectiveness and the quality of the transformation process and the outputs.

Normally, economic justification and payback of CIM projects is one of the hardest parts of the process. This model could be used to estimate other points of performance measurement that could be affected positively. Improvements in quality and flexibility could improve the organization's competitive position and overall strength.

3.2.1.3. Specify Organizational Design Dimensions

At this point, the type of production system and the expectations about its performance are known, so at this time the organizational structure is adjusted according to the principles explained in *3.1.4.*

3.2.2. Technical Work Process and Unit Operations

3.2.2.1 Identify Unit Operations

Unit operations are groups of tasks that conform a whole and are separated from other unit operations. They usually have distinctive outputs and a group of workers assigned to them. In a CIMS environment, at the production level, FMS cells can conform unit operations if the machining centers are equivalent. If they have distinct operations that can only be performed in certain centers within the FMS, then those will be considered unit operations by themselves. Usually end-of-line work centers like deburring, washing, painting and inspection/measurement can be considered unit operations on their own.

The identification of unit operations also helps in the configuration of the physical layout and also in equipment-related decisions, because a unit operation does not have to be necessarily tied to one machine or workstation, so at this point different alternatives of equipment selection can be considered.

3.2.2.2. Flowchart the technical work processes

The purpose of this step is to identify the structure and sequence in which the process that transforms inputs into outputs is carried out. This identification helps to define tasks, to specify the flow of each product (or family of products) and to give the right context to the assignment of functions.

In a CIM environment, this can help to configure the ways in which the process will be automated, the types of information that are required and generated at each step of the process, the logical grouping of machines into cells and the boundaries that will be established between departments or cells.

3.2.3. Collect Variance Data

Variance occurs when something in the process behaves in an unexpected or undesired fashion. Identifying variances is important because it will allow the analysts to assess the critical points for improvement (prior to implementation of CIMS) that will need to be addressed, and (after implementation) it will also enable the collection of data to identify problem causes in operation.

Variances are also the gaps between the way the processes are supposed to be performed and the way they are actually performed. These discrepancies demand action in one of several possible levels:

- Revise the standard process: It might happen that the way the process is written is not the most adequate or efficient. Operators can find better ways to perform their work, and these can be studied and standardized.
- Retrain the worker.
- Revise the availability of the right tools and equipment. Also assess the need and availability of operational information, which can be an area improved by a CIMS implementation.

3.2.4. Construct Variance Matrix

As with many other phenomena, it is very common that a few of the causes account for the majority of the outcomes or symptoms (Pareto's principle). These phenomena will be identified as *key variances*, and they are the ones that should be addressed with priority.

To achieve this goal, for each unit operation a *variance matrix* must be constructed, showing the relationship between the variances. Then, it will be observed that a subset of the variances (usually between 10 and 20%) account for many of the problems. These variances that affect greatly the throughput, quality, cost, work satisfaction or safety are the key variances. A sample of a variance matrix can be seen in **Figure 6.**

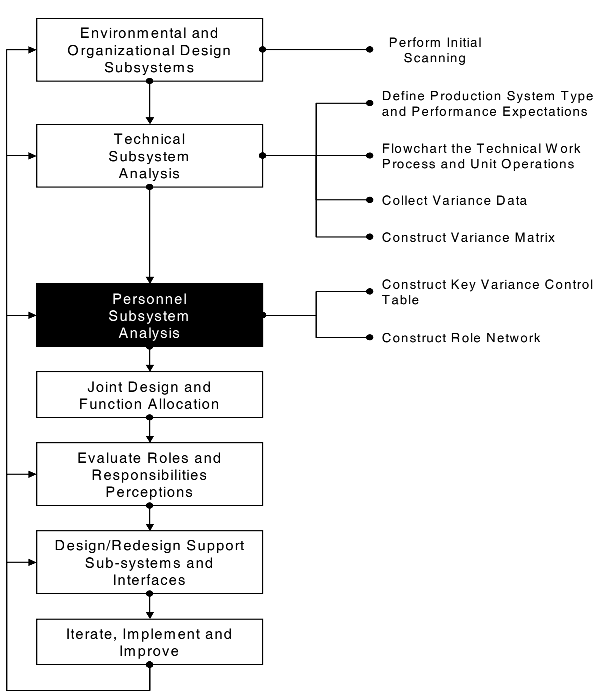
Unit Operation	**Metal stamping**					
	1. Temperature of metal sheets	1				
	2. Size of metal sheets	X	2			
	3. State of the tooling			3		
	4. Pressing speed	X	X		4	
	5. Pressure on press	X		X	X	5

Figure 6: Sample of a Variance Matrix for Metal Stamping unit operation

In the sample variance matrix displayed in **Figure 6**, after examination of the relationships it was decided that the *Temperature of metal sheets* (input) and the *Pressure on the press* (process) are the key variances, meaning that if these factors are addressed and controlled to stay in their desired levels, the rest of the variances will be reduced considerably.

In CIM environments, this table will be useful to detect critical parameters in the transformation process, as well as in all the other processes involved in the manufacturing of the products. Unit operations like Product Design, Process Planning, Production Planning and so on can be analyzed using this method to find critical improvements and control points required to ensure the correct operation of the system.

3.3. Personnel Subsystem Analysis



3.3.1. Construct Key Variance Control Table

In this table the key variances identified in the previous step are examined considering who is in charge of controlling them and what would be their requirements in terms of control tasks, technology and information and social support. This will give the analysts a good idea about the tools, information and support systems that need to be made available to people performing the operations. A Sample Key Variance Control Table is shown in **Figure 7.**

Also, the Key Variance Control Table is useful to identify requirements for information systems, computerized or otherwise, because it will let the analysts observe what is required in terms of information to perform the operations in a manner that minimizes the effect of the key variances.

Key Variance	Unit Operation	Who's responsible ?	Control Tasks	Technical Support	Social Support
Temperature of metal sheet	Metal Stamping	Operator	Temperature Measurement	Digital thermometer, MH equipment	Process guidelines on temperature, measurement procedures
Pressure on Press	Metal Stamping	Operator	Verify pressure	Better parameter displays	Training, procedures for pressure settings.

Figure 7: Key Variance Control Table

In CIM environments this another good place to find requirements for the information system, equipment and automation. For instance, if it is discovered that the source of a key variance is the variability in measurements due to human interpretation of the displays, then partial automation of the measurement could reduce the "human interpretation" component of the variance.

3.3.2. Construct Role Network

The Role Network is a graphical depiction of the interactions between different individuals in the work system. In it, the people involved will be identified with respect to their relationship to the *focal role*, which is the person in charge of controlling most of the key variances, the person without whom the system would not function.

The Role Networks can be drawn at several scope levels, in each case going into the details of the system. For example, a focal role can be the President of the company, and his/her immediate relationships might be with the Vice-presidents. On turn, the VP of Manufacturing can be the focal role for the whole manufacturing area, so a Role network would be developed for manufacturing. An example of Role Network is shown in **Figure 8.**

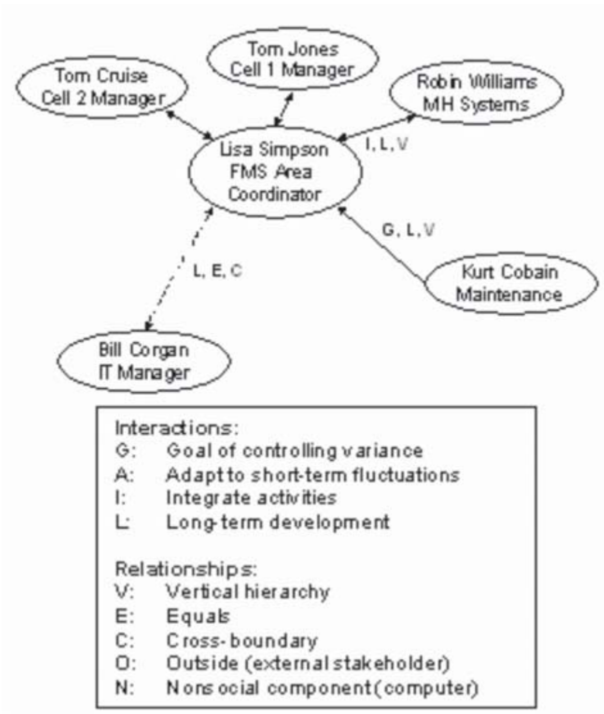


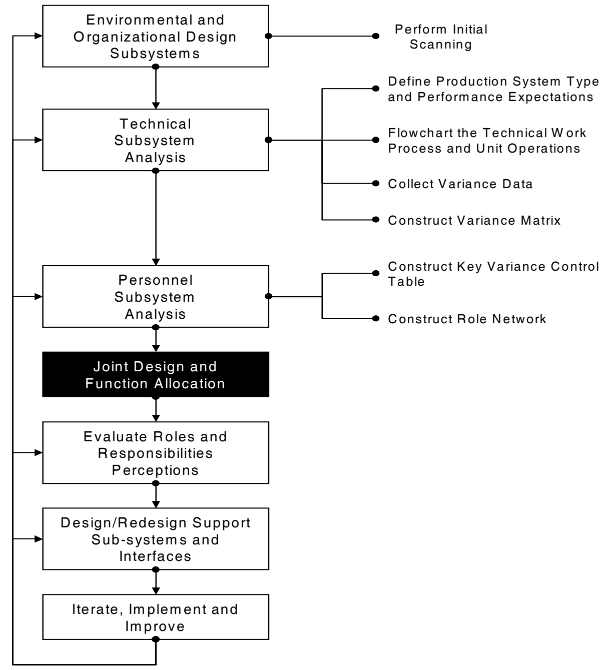
Figure 8: Role Network for Famous People Manufacturing

In these networks, the direction of the arrows show the direction of communication, and the proximity to the focal role (Lisa Simpson, always in the center) shows the importance and frequency of the relationship. Also, text key signals are used (explained next to the network) to characterize the interactions and the type of relationship between each actor and the focal role.

In CIM environments, the Role Network can be used to check for discrepancies between whatever the relationships are supposed to be according to the formal structure of the company and what they really are. This would make some changes in position and formal responsibilities necessary, but it is important that the formal structure of the company reflects the actual operation in terms of variance control.

3.4. Joint Design and Function Allocation

At this point, the main technical processes have been described and there is a general organizational structure proposed for the company. Function allocation is the process of assigning tasks to people, machines and computers.



Traditionally, the urge to **automate as much as possible** to save on direct labor costs has been a driven in automation processes. This approach falls in the category of a "pitfall" of organization design, characterized by macroergonomists as the "leftover approach", in which tasks are allocated first to machines or computers based on their capabilities and whatever was left was assigned to humans. This results in mechanical, fragmented tasks that go against several of the sociotechnical principles, like "boundary management", "multi-skilling" and "designee and human values". This type of assignment results in low worker satisfaction, lower intrinsic motivation and therefore in increased absenteeism.

To address this, several function allocation models have been developed with different levels of complexity. An example of this is the model developed by Mital (1997), which suggests some criteria to decide if the task is allocated to human or machines. According to Mital, some tasks **must** be assigned to machines because of

- design accuracy and tolerance requirements;
- the nature of the activity is such that it cannot be performed by humans (e.g. water jet cutting, laser drilling);
- speed and high production volume requirements;
- size, force, weight and volume requirements (e.g. materials handling);

- hazardous nature of the work (e.g. welding, painting);
- special requirements (e.g. prevent contamination).

Accordingly, some tasks **must** be performed by humans because of

- information-acquisition and decision-making needs (e.g. supervision, some forms of inspection);
- higher level skill needs (e.g. programming);
- specialized manipulation, dexterity, and sensing needs (e.g. maintenance);
- space limitations (e.g. work that must be done in narrow and con® ned spaces);
- situations involving poor reliability equipment or where equipment failure could be catastrophic;
- activities for which technology is lacking (soil remediation), etc.

And this leaves some functions that can be performed by machines **OR** humans:

- assembly of parts and subassemblies;
- routine on- line inspection;
- packaging and shipping;
- palletizing and stacking;
- materials handling;
- sorting.

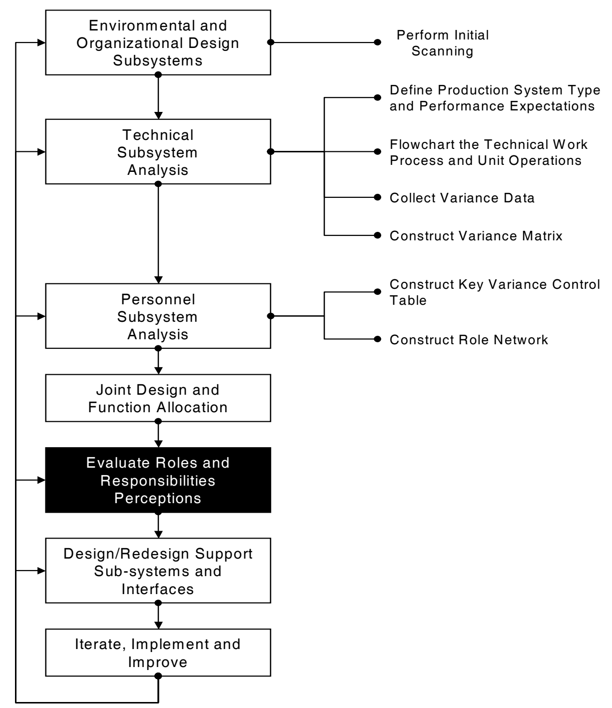
It is especially over these that the sociotechnical criteria must be applied more carefully to ensure that the resulting jobs are interesting and fulfilling.

In a CIMS environment, the natural grouping in FMS cells provides many opportunities to assign teams to work cells and from there, through cross training and teamwork, develop a participatory scheme to decide on function allocation. A positive aspect is also the correspondence of work cells to product families, because it allows cell teams to acquire ownership and completion of work, to visualize and be able to track their performance through finished products (at least finished by their part of the process).

Higher level functions like new product conception, problem solving, maintenance and improvement of the system and final quality decisions should be kept to humans. The system and computers should be used to effectively assist humans to do their jobs.

Human teams should also be given a fair amount of autonomy in the way they organize themselves, their work, and their interaction with the automated system, to be consistent with the sociotechnical principle of minimum critical specification.

3.5. Evaluate Perceptions of Roles and Responsibilities



It is necessary to confirm with the workers and people involved in the transformation of the company the proposed design of the organization and the roles hypothesized by the team of analysts. There is bound to be some discrepancies between the two sets of roles.

At this point, the Variance Matrix and the Key Variance Control Table are important to ensure that the roles constructed are accurate and are consistent with the perceptions of the people actually involved in the process. The gaps between expected roles and perceived roles can be addressed through training and reassignment of personnel.

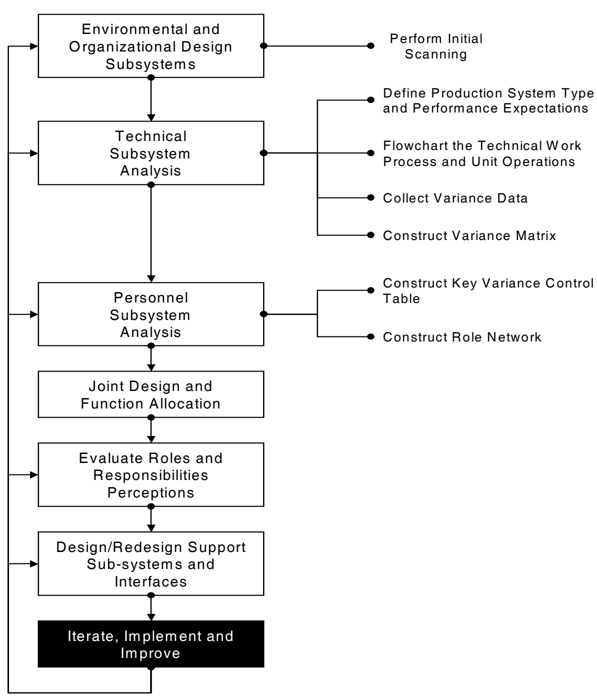
For example, in a given cell the focal role should be (by design) the Cell Team Leader or Cell Manager, but after the construction of the Role Network it is found that the focal role is actually a Supervisor. Also, the Cell Manager is creating variances instead of controlling them. In this case, it would be advisable to either train the Cell Manager to fulfill his/her duties adequately or “deselect” him/her and train the Supervisor to take the position of Cell Manager.

3.6. Design Support Subsystems and Interfaces

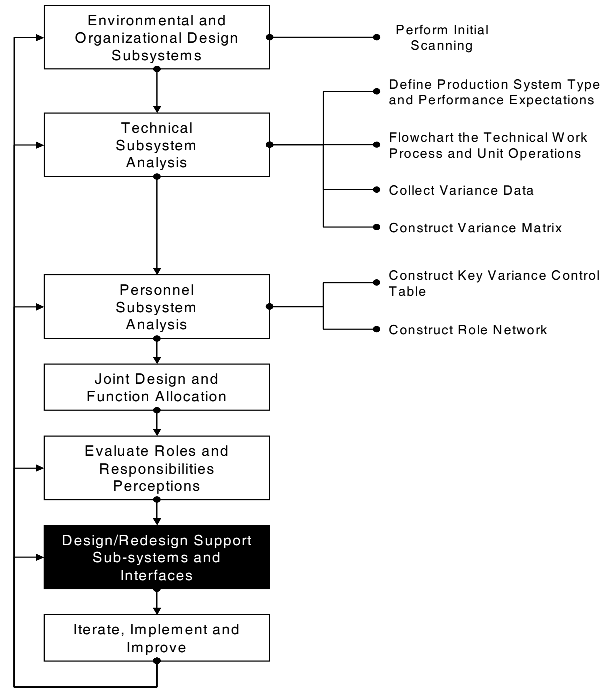
All this methodology has addressed primarily the design or redesign of the main technical processes, the “production” side of the organization. At this point, it is necessary to go over all the support systems that make possible the operation of the company and to revise them in light of the macroergonomic considerations employed with the production processes.

Subsystems like information systems and personnel-reward systems should be assessed in their functionality and also in their relationship with the main processes. In a CIMS implementation this would be the right point in the design process to go over all the functional requirements and specifications of the information system, to support all the users with the information they require presented in an accessible and usable format, to ensure the standard CIM requirements like traceability and data integrity and to be an enabling tool instead of a liability (which many information systems are).

3.7. Iterate, Implement and Improve



As with any dynamic organism, the nature of the organizations is not static. Organizations are in constant change and evolution, and consequently the organizational structure, the assigned roles, the allocation of tasks and functions must be in constant revision.



In particular, organizations have to be very aware of the changes and trends in their environment, because it shapes the way business and competition will occur, the way markets behave and the different courses of action available for companies to continue striving for competitiveness. Stillness brings stagnation.

4. Conclusions

- Many CIMS implementations have failed because of the failure to recognize and address the organizational and human issues of large-scale technological change. Large-scale changes include not only CIMS implementations, but also ERP projects and changes geared towards the human side of technology, such as Lean Manufacturing and Six Sigma implementations. The Sociotechnical Systems Theory provides a sound theoretical an empirical background to analyze work systems and to manage and implement any type of enterprise-wide project of change.

- Macroergonomics was born from the Sociotechnical Systems School and proposes an integrated framework to analyze, design and improve work systems. For academics, practitioners and students in various engineering fields Macroergonomics provides guidelines that are easy to understand. This is important because engineers have been accused of ignoring the human side of organizations at worst, and oversimplifying and mechanizing it at best. A thorough understanding of people, their interaction with the sociotechnical systems and their outlook on work and change are crucial for a more productive relationship between engineers and organizations, and since it is not uncommon for engineers to be promoted to managerial roles, it could be argued that the study of Macroergonomics is advantageous to both individuals and organizations.

- The application of the MacroErgonomics Analysis and Design process (MEAD) to the implementation of CIMS recognizes and addresses in a systematic fashion the problems related to organizational design, human-systems interfaces and function allocation between humans and machines. Therefore, it is a subject worth further investigation, application and discussion, especially in engineering faculties that have traditionally struggled to understand the intricacies of working with people.

5. Areas for Future Research

- In the technical literature there are theoretical models relating CIMS and sociotechnical systems, also CIMS and psychological studies of work, but a model proposing the application of the MEAD (MacroErgonomics Analysis and Design process) to the implementation of a Computer Integrated Manufacturing System was not found. Therefore, it seems relevant to further explore the theoretical soundness of the model and also try to find empirical evidence to support its validity and applicability.

- CIMS is an interesting field of study for teamwork researchers in its different specialties, because of its fundamentally cellular approach to manufacturing. The cells are natural units that do not require the establishment of additional artificial boundaries. Therefore, all the different subjects of teamwork, quality circles, autonomous workteams and similar themes can learn a great deal and also improve the design and performance of CIM systems.

6. Bibliographical References

1. Bailey, R.W. (1989). Human Performance Engineering (2nd ed.). Englewood Cliffs, Prentice-Hall.
2. Cleland, D. I., Bidanda, B., and Chung, C. A., 1995, Human issues in technology implementation-Part 1. Industrial Management, 37, 22- 26.
3. Dale, L. (1995). *Human Factors and Sociotechnical Systems in Computer Integrated Manufacturing.* Proceedings of the Aerospace Applications Conference, 1995. IEEE, Issue: 0, 4-11. Pages:201 - 214 vol.2
4. Hendrick, H.W. (1998). Macroergonomics: A systems approach for dramatically improving occupational health and safety. In S. Kumar (Ed.), Advances in occupational ergonomics and safety 2 (pp. 26-34). Amsterdam, IOS Press.
5. Mcgaughey, R.E. Roach, D. (1997). Obstacles to computer integrated manufacturing success: a study of practitioner perceptions. *International Journal of Computer Integrated Manufacturing, 10 (1-4),* 256-265.
6. Mital, A. (1997). What role for humans in computer integrated manufacturing?. International Journal of Computer Integrated Manufacturing, 10 (1-4), 190-198.
7. Oborski, P. (2003). Social-technical aspects in modern manufacturing. *International Journal of Advanced Manufacturing Technology, 22,* 848–854.
8. Pardo, O., et.al. (1995) Computer-aided manufacturing systems: Work-psychological aspects and empirical findings from case studied. International Journal of Industrial Ergonomics, 16, 327-338.
9. Perrow, C. (1967). A framework for the comparative analysis of organizations. American Sociological Review, 32, 194-208.
10. Robbins, S.R. (1983). Organization Theory: The structure and design of organizations. Englewood Cliffs, NJ, Prentice-Hall.
11. Saraph, J. V., snd Sebastian, R. J., 1992, Human resource strategies for eff ective introduction of advanced manufacturing technologies (AMT). Production and Inventory Management
12. Sink, D.S., Tuttle, T.C. (1989). Planning and Measurement in your organization of the future. Norcross, GA: Industrial Engineering and Management Press.