ERGONOMICS IN THE EVALUATION AND SELECTION OF ADVANCED MANUFACTURING TECHNOLOGY

Aidé Maldonado-Macías[1,2], Jorge García Alcaraz[1], Cesar Omar Balderrama, Rosa María Reyes[2], Jaime Romero Gonzalez[1]

Universidad Autónoma de Cd. Juárez
Ave. Del Charro 405 Norte
Cd. Juárez, Chih.
amaldona@uacj.mx

División de Estudios de Posgrado e Investigación
Ave. Tecnológico 1340
Cd. Juárez, Chih.

Abstract: This paper presents a theoretical study and a literature review of important ergonomic issues on the selection of Advanced Manufacturing Technology (AMT). Due to actual models for planning, evaluation and justification of AMT are found to be incomplete in order that ergonomic attributes of the equipment are obviated or underestimated. In this way, problems related with automation and AMT are exposed in this work. Also the ergonomic attributes that must be considered in the AMT selection are explained from an extensive literature review. Finally an ergonomic compatibility approach is described using the Ergonomic Compatibility Model for the selection of AMT from a multi-attribute perspective.

Resumen: Este documento presenta un estudio teórico y una revisión de la literatura sobre aspectos importantes en el campo de la Ergonomía implicados en la selección de Tecnología de Manufactura Avanzada (TMA). La industria moderna ha incrementado sus inversiones en esta tecnología, sin embargo; los modelos actuales de planificación, evaluación y justificación de TMA se consideran incompletos ya que los atributos ergonómicos requeridos en los equipos generalmente son obviados o subestimados. Por lo tanto, algunos problemas relacionados con la TMA y la automatización se describen en esta investigación. Así mismo, los atributos ergonómicos que deben tomarse en cuenta en la selección de TMA son expuestos a partir de una revisión de la literatura. Por último un nuevo enfoque ergonómico de evaluación de esta tecnología se describe mediante el Modelo Evaluación de Compatibilidad Ergonómica (MECE) para la selección de TMA desde una perspectiva multiaributo.

Palabras Clave:
Ergonomics, Ergonomic Compatibility Attributes, Advanced Manufacturing Technology
Ergonomía, Atributos Ergonómicos, Tecnología de Manufactura Avanzada.

1. INTRODUCTION

Advanced Manufacturing Technology (AMT) is regarded as one of the most critical resources of manufacturing companies in the world to achieve competitiveness. The constant and rapid evolution of the AMT has led to the manufacturing sector towards progressively automated processes. Historically, this development was originally led by a technical centered approach, yet the results have not been entirely satisfactory; reason why it has been developed a new human-centered approach, in which the capabilities and limitations of the human being must be integrated and taken into account in the design, as well as the evaluation, selection and implementation of this technology. The ergonomics is the science whose purpose is entirely appropriate for this approach, because it promotes the understanding of the capabilities and limitations, thereby contributing to the design of most human-compatible systems. Actual models for evaluating and selecting AMT are scarce of the ergonomic approach which can includes multiple ergonomic attributes that must be considered to guide a more complete decision on the acquisition of equipment, so it is considered that the ergonomic science and its principles should have a more active intervention on evaluation processes for the selection of AMT. This document presents a review of reflective literature which develops the theme of ergonomics in the selection of AMT. A great opportunity for research in this area is overlooked and therefore this work aims to develop the relevant topics associated with the ergonomics science and its intervention to support the processes of evaluation and selection of this technology in decision making processes.

2. THE CONCEPT OF ADVANCED MANUFACURING TECHNOLOGY

Although the AMT is for Säften (2007) the collective name given to modern technology integrated to manufacturing, it includes Computer Aided Manufacturing (CAM), Computer Numerical Cotrolled (CNC), and the Flexible Systems for Manufacturing. For Rao (2007), also includes robotics, rapid prototyping, environmentally sustainable technologies, among others. Boyer et al. (2000), classify it according to its areas of application, which are: design, manufacturing and administration. Computer-aided engineering and CAD (Computer Aided Engineering) are examples of the first one; while CAM, robotics, control systems process in real time, FMS and the automated systems of materials handling, are examples of the second one. Finally, the use of internet to support decision-making systems, Material requirements planning and Material Requirements Planning (MRP), are examples of the application for the administration. According to Bayo-Moriones and Díaz (2004), Saraph and Sebastian (1992), this technology has promoted a transcendent change in the competitive strategies of manufacturing companies. Companies are interested in AMT since they can obtain a combination of flexibility, efficiency and quality in such a way that they can minimize significantly, costs and optimize the quality. According to Dean and Snell (1991) the most important feature found is related to its potential to integrate the different stages of the process of manufacturing. As a result, the manufacturing of large volumes of standardized products, or small batches with high quality (Gyan-Baffour, 1994) can be afforded. In summary, AMT is such technology generally related to the use of the computer, which can be integrated in manufacturing operations having a significant impact on the product, process and information aspects of the system.

3. RELEVANT TOPICS ABOUT ERGONOMICS IN THE SELECTION OF AMT

In this part it is presented a discussion about the relationship between human and AMT and the relevance of human intervention. Also, it is explained that Human Factors and Ergonomics are aspects that have been relegated in actual models for AMT selection and evaluation, consequently there are important health and safety implications related to AMT.

3.1 Human and AMT: an interdependent relationship

For Vincent (1999) the technical-centered approach has historically dominated the integration of the AMT within a system where people interact in a dynamic environment with incomplete and uncertain information, in which there are unexpected problems and actions are computer-mediated creating complex socio-technical systems. According to Kesseler (2006) the technical-centered approach describes that systems provide what is technically possible (Automation) without sufficient and adequate attention to the interaction with human beings and because failures are often unexpected, designers have reduced but not eliminated, human intervention. While the human intervention has been reduced or nullified, human beings have been affected in different ways, including the crucial adaptation of workers to new skills. To this end, the physical abilities are now superseded by the cognitive, reducing its capacity and experience in the operations which are now automated, (Mital and Pennathur 2004 and Reason 1990).

For Endsley (1993), Siemieniuch and Sinclair (1995), human skills are still needed, and are even more critical than before, due to a complex man-machine system. These human skills usually are required for management of heterogeneous equipment, multimedia databases with operations in real time, monitoring task, other tasks that require anticipation, judgment, rapid diagnosis, programming, maintenance and adjustment, quality control and rapid intervention in difficult situations. According to Wobbe (1990), when tasks cannot be automated or are complex and require assessment and judgment the human being is able to perform them with relative efficiency. Therefore, human beings and the AMT maintained an interdependent relationship and to achieve a successful implementation of this technology, capabilities and limitations, must be taken into account as an integral part in the recent advanced manufacturing systems. Currently, a new human-centered approach has been created where ergonomics plays a crucial role (Mital and Pennathur, 2004). In this regard, the role of humans is more important than before, particularly by the relevance of the intervention and the high costs related to errors in the man-machine system. In this regard, Wiener and Curry (1980), Moray (1986), Billings (1991), Sarter and Woods (1995) and Kaber (2004), Ramachandran and Naadmuthu (1989), Lee and Salvendy (2006), report serious problems associated with the man-machine system errors and attribute them mainly to the decrease attention about the intervention of the human being in complex systems and automation, where the AMT can be located. They claim that while it was introduced among other reasons to reduce human errors, heavy and repetitive tasks, new forms and more critical error and dangerous situations have ironically resulted as a consequence.

About this discussion, models that assist decision making processes during planning and evaluation phases even on the early stages of AMT design present a lack of attention on ergonomic attributes. In this matter; the interaction of AMT with human is a very interesting and important topic to be attended in the Ergonomics field and research.

3.2 The ergonomic approach: a relegated aspect in the selection of AMT

This section contains theoretical evidence that reveals the lack of the ergonomic approach in the selection of AMT. According to Wobbe and Charles (1994), about the functions of planning, selecting and implementing of AMT; traditional economic models are largely used. About the selection function in particular it is mainly executed with the criteria of cost and return on investment, however; in some cases it has been informed about the improper operation of AMT and low productivity.

In these functions, the ergonomic aspect is usually omitted or neglected, and when it comes to be considered, is limited to analysis for reduction of labor costs. Ayres et al. (1983), Majchrzak (1988), Butera (1984), Susman and Dean (1992) notify that in the implementation phase of AMT, ergonomics and human factors issues are usually ignored or relegated having just a reactive approach to the arising problems.

For Talluri and Yoon (2000), the evaluation of AMT is an important problem, because of the elevated and critical of the investments. Also, because the processes and procedures implicated in it are complex and strategic, involving multiple decision variables, moreover, the critical attributes of performance are not known precisely, as well of the preference relations among them; and appropriate models for this purpose are scarce.

Several ergonomic and safety problems are associated with AMT design. In this topic, Karwowski (2006) comments that even when Ergonomics is a design-oriented discipline, the ergonomists do not design systems, but those interactions between humans and the systems-artifacts. He recognizes that ergonomists and the ergonomics discipline must have a more participative role in the design of these systems.

On the other hand, with regard to the planning and selection of AMT, current models for decision making, obviate or relegate the ergonomic aspect. The decision makers are not aware of the relevant ergonomic attributes of AMT therefore, they cannot include them effectively. Also they continuously face the problem of selection among several alternatives and sometimes they do it with incomplete or vague information.

So, we can say that science constitutes the driving force of the growing evolution of AMT and it promotes the emergence of new application of more efficient and cleaner technologies, even free of the human being intervention. However, on its implementation and operation, human factors and ergonomics aspects should be included to enhance systems´ performance.

3.3. The health risks associated with the AMT

According to Karwowski (1990,2005), safety and health issues associated with complex manufacturing systems, are critical aspects for their design and operation. In the study of the AMT, other aspects such as human factors, reliability and safety, must be in taken into account in addition to the technical aspects. Human Factors and Ergonomics aspects have been underestimated in the control of injuries and accidents, In accordance to Ayres and Miller (1983), Masterson (1987), Zimolong and Duda (1992) there is insufficient and/or incomplete information related with the health and safety of AMT systems. These aspects have been relegated in their importance and there are difficulties in determining the magnitude and potential impact of the AMT in terms of health and safety. For Nicolaisen (1985), Sugimoto and Kawaguchi (1985), Karwowski et to al. (1988), and Karwowski (2005); the reason for this, is that a high percentage of accidents related with AMT are not registered. Likewise, it is difficult their identification in the available statistics, because they are mixed among the classification of accidents caused by other kind of reasons linked with some other equipment, machine or tool.

Only very few studies were found related with this topic, like the one of Sugimoto (1987) and the Ministry of Labor in Japan, where robots failures have caused hazardous conditions at work resulting in injuries and even fatalities. Most failures of AMT systems take place when programming, cleaning and maintenance tasks are performed; in this way, they have been identified as the main sources of these hazards and risks according to authors like Wilson et. al. (1994, Backström and Harms-Ringdahl (1984), Chan and Courtney (2001) and Jiang and Gainer (1987).In such a way, in accordance with Sugimoto (1987), and Chan and Courtney (2001), there is a generalized misunderstanding of the nature of the automation and AMT; and there are false beliefs about its safety. Therefore, an increased attention on these topics is needed.

Furthermore, it is relevant to denote that most of the available information is in the AMT implementation phase, but has not been considered for the evaluation of AMT on planning and selection phases; which would represent a strategic advantage when selecting technology. In addition to these difficulties, there is a lack of modeling of costs associated with health and safety benefits. These include the works of Oxenburg (1991) and Anderson (1992) who proposed guidelines to reduce these costs. They also propose a model to estimate the return of ergonomic investments. However, there is a lack of procedures to compare alternatives in terms of health and safety to justify such investment.

4. IMPORTANT ERGONOMIC ATTRIBUTES FOR THE SELECTION OF AMT

Ergonomic attributes for the selection of AMT concern to human´s capabilities and limitations in interaction with this technology, as well as the effects of ergonomic incompatible equipment and the consequences of the error by design. AMT systems are highly complex and requires of considerable amount of cognitive tasks in everyday work. Human beings by nature have limitations; among the most important ones are: their limited working memory, slow performance of cognitive operations, and information retrieval, numerical operations and time and space orientation. These constraints must be taken into account when selecting alternatives of AMT, especially the ones related with monitoring tasks where problems associated with mental workload may carry out considerable downtime affecting production times, Endsley (1993).

On the other hand, Mital and Pennathur (2004) reported that most of automated equipment does not comply with basic guidelines for interface design; engaging inefficiencies on both equipment and human operator. Conversely an efficient interface will reduce the mental workload, eliminate or minimize human errors, will prevent confusion and will reduce the cost of the time consumed by such inefficiency. It can be said that the human being is still the most versatile and flexible element in the manufacturing system. In addition, they point out that it is unlikely that machines can perform functions with variable information in real time; at least in the near future; consequently humans will have an important role in advanced manufacturing environments. In this way the implementation and successful adoption of AMT depends crucially on human intervention, so ergonomics aspects must be included and objectively evaluated during the selection of alternatives of AMT. According to Corlett and Clark (1995), the main interactions between humans and machines can be summarized in Figure 1 showing the major components. Ergonomics is concerned about the study of interfaces and interactions between the human operator and other of its components as well as the effects of such interactions in the performance of the system.

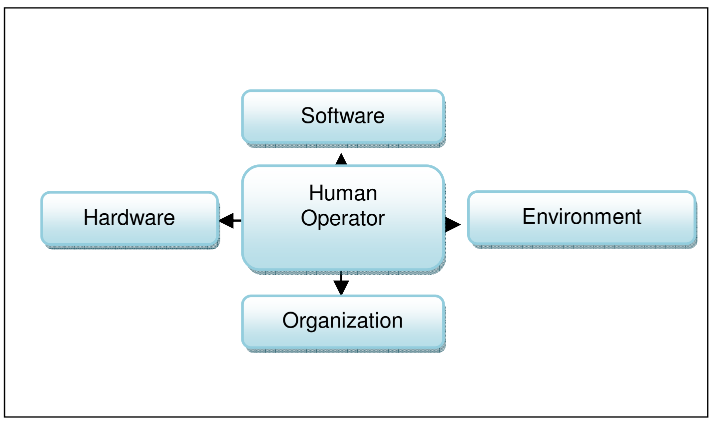

Fig. 1 Interactions in Human-Machine Interface

In this system, the Hardware (physical ergonomics), refers to the machine design intended for improved operation, maintainability, and safety. The software (cognitive ergonomics), refers to the design of visual displays and instructions, labels, symbols, tables, computer and manual programming. The Environment refers to noise, vibration, temperature and lighting emitted by the machine. Finally the Organization element refers to the content of the work, work methods, rate of production, cycle time, pace of work associated with the interaction of the machine and the human being.

Ergonomic Compatibility Attributes for the selection of AMT

In this part, the Ergonomic Compatibility Attributes are described according with the Ergonomic Compatibility Evaluation Model for the selection of AMT proposed by Maldonado (2009). This model is a multi-attribute approach that combines in an innovative way the Axiomatic Design Theory in Ergonomics and the Fuzzy Logic Theory fundamentals to evaluate and compare alternatives of AMT from an ergonomic perspective.

Ergonomic Compatibility (EC) is a construct used in this model and it is defined evoking the concepts of human-system and human-artifact compatibility introduced by Karwowski (1997, 2001, 2005), who offers a comprehensive treatment of compatibility in human factors discipline. It intends to measure in a subjective way, the probability of a design to satisfy ergonomic requirements using the Ergonomic Incompatibility Content (EIC). The EIC is an index obtained by the adaptation of the Information Axiom in the Axiomatic Design Theory. Ergonomic Compatibility attributes are not precisely determined in the literature, also involves the evaluation of multiple quantitative and qualitative aspects, so complexity and vagueness are involved. For Karwowski (2005), advanced technologies with which human interact constitute complex systems that require a high level of integration, he considers that Ergonomic Compatibility Attributes of AMT have to focus in the design integration of the interactions between hardware (computer-based technology), organization (organizational structure), information system, and people (human skills and training). Maldonado et. al. (2009) presents the set of attributes for Ergonomic Compatibility Evaluation based on an extended literature review and the ergonomic factors proposed by Corlett and Clark (1995). Ergonomic Compatibility Attributes are presented bellow in Figure 2.

- (A11) **Human Skills and Training Compatibility**
  - (A111) Skill Level Compatibility
  - (A112) Training Compatibility
- (A12) **Physical Work Space Compatibility**
  - (A121) Access to Machine and Clearances
  - (A122) Horizontal and Vertical Reaches
  - (A123) Adjustability of Design
  - (A124) Postural Comfort of Design
  - (A125) Physical Work of Design
- (A13) **Usability**
  - (A131) Compatibility with Controls´ Design
  - (A132) Controls' Physical Distribution
  - (A133) Visual Work Space Design
  - (A134) Information Load
  - (A135) Error Tolerance of Design
  - (A136) Functional Allocation of Design
  - (A137) Design for Maintainability
- (A14) **Equipment Emissions Requirements**
  - (A141) Temperature
  - (A142) Vibration
  - (A143) Noise
  - (A144) Residual Materials
- (A15) **Organizational Requirements**
  - (A151) Compatibility with Rate of Work
  - (A152) Compatibility with Total Work Content

Fig.2 Atributos de Compatibilidad Ergonómica en la Selección de la TMA

The model presents a hierarchical structure with five main attributes and twenty sub attributes. Also, the work of Maldonado et. al. (2010) is recommended for further reading. This scheme is shown below in Figure 3.

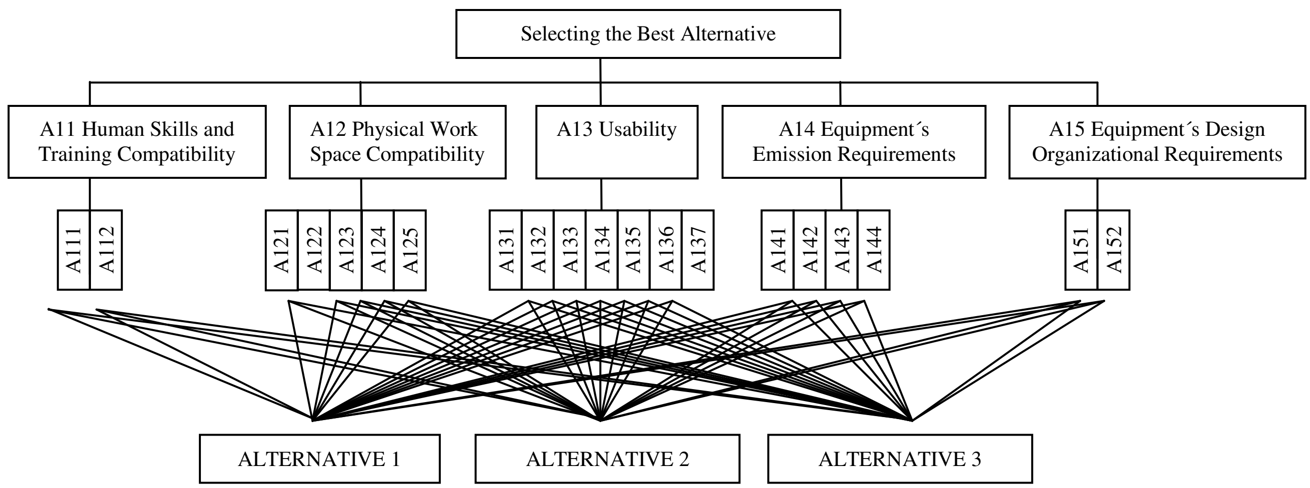

Figure 3. Selection of the Best Ergonomic Alternative

5. CONCLUSIONS

It can be concluded that the purpose of this paper has been accomplished in the way that comprehensive literature review have been exposed and important topics related with human factors, ergonomics and AMT were discussed. The increased application of AMT and other automated systems in industries worldwide have change the role of human intervention in the human-machine system intensifying its relevance and developing new skills. This role is even more important than before due to the highly automated operations which requires now of more cognitive demanding tasks rather than physical demanding tasks. The significant investments on AMT requires a more effective and successful implementation of it. Also the human errors and errors by design consequences, in addition to the elevated costs associated with them have been topics of interest for the Ergonomics science. However, actual models for evaluating and selecting technology are scarce of the ergonomic perspective; and a more pragmatic approach is necessary. Decision makers for AMT are often unacquainted of important ergonomics aspects; models that can include them effectively to support their decisions are also scarce. In this way, a novel model for this purpose has been presented in this paper and may contribute to this problem by means the application of the model and its validation in industry.

6. REFERENCIAS

Andersson, E.R. (1992). Economic evaluation of ergonomic solutions: Part-1: Guidelines for practitioner, International Journal of Industrial Ergonomics, Vol. 10, pgs. 161-171.

Ayres, R. U., y Miller, S.M. (1983). Robotics: Application and Social Implication, Harper & Row, Nueva York, Estados Unidos de América.

Backström, T., y Harms-Ringdahl, L. (1984). A statistical study of control systems and accidents at work, Journal of Occupational Accidents, Vol. 6, pgs. 201-210.

Bayo-Moriones, A., Merino, J. (2004). Employee Involvement: Its Interaction With Advanced Manufacturing Technologies, Quality, Management, and Inter-Firm Collaboration. Human Factors and Ergonomics in Manufacturing, Vol. 14 (2), pp. 117-134.

Billings, C. E., (1991). Human-centred aircraft automation: A concept and guidelines, (NASA Tech. Memo. No. 103885) (Moffet Field, CA: NASA-Ames Research Center).

Boyer, K. K. y Pagell M.. Measurements issues in empirical research: improving measures of operations strategy and advanced manufacturing technology. Journal of Operation Management, Volumen 18:3 pgs. 361-374.

Butera, F. (1984). Designing work in automated systems: A review of case studies, en Automation and Work Design, F. Butera y J.E. Thurman, (Eds), Elsevier Science, Nueva York, Estados Unidos de America.

Chan A. H.S., Courtney A. (2001). Safety and ergonomics evaluation of hybrid systems in Hong Kong, Accident Analysis & Prevention, Vol. 33, pgs. 563-565.

Corlett E. N. y Clark T.S. (1995). The Ergonomics of Workspaces and Machines, 2a. Edición, Taylor and Francis.

Dean, J., y Snell, S. (1991). Integrated manufacturing and job design: Moderating effects of organisational inertia. Academy of Management Journal, 34(4), 776-804.

Endsley, M. R. (1993). The integration of human and advanced manufacturing systems, Journal of Design and Manufacturing 3, pgs. 177-187.

Gyan-Baffour, G. (1994). Advanced manufacturing technology, employee participation and economic performance: An empirical analysis. Journal of Managerial Issues, 6(4), 491-505.

Jiang, B.C., Gainer, C.A. A cause-and-effect analysis of robot accidents, Journal of Occupational Accidents, Vol. 9, pgs. 27-45.

Kaber, D. B., y Endsley Mica R. (2004). The effects of level of automation and adaptive automation on human preformase, situation awarness and the workload in a dynamic control task, Theorical Issues in Ergonomic Science, Taylor and Francis Vol. 5, No.2, pgs. 113-153.

Karwowski W. (1991). Complexity, Fuzziness, and Ergonomic Incompatibility Issues: The Control of Dynamic Work Environments, Ergonomics, Vol. 34, No. 6, pp. 671-686.

Karwowski W. (1990). Injury control and worker safety in integrated manufacturing systems, Unpublished Technical Report, Center for Industrial Ergonomics, University of Louisville, Louisville, Kentucky, Estados Unidos de América.

Karwowski W. (2006). On measure of the Human-System Compatibility, Theoretical Issues in Ergonomics Science.

Karwowski, W. (2000). Simvatology: The science of an Artifact-Human Compatibility, Theoretical Issues in Ergonomics Science, Vol. 1, Nol. 1, pp. 76-91.

Karwowski W. (2001). International Encyclopedia of Ergonomics and Human Factors, Taylor & Francis, London.

Karwowski W. (2005). Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems[1], Ergonomics, Vol.48, No. 5, Pgs. 436-463.

Karwowski, W., Parsaei, H.R., Nash, D.L., and Rahimi, M. (1988). Human perception of the work envelope of an industrial robot, en Ergonomics of Hybrid Automated Systems, W. Karwowski, H. R. Parsaei, and M. R. Wilhem, Eds., Elsevier, Amsterdam, pgs. 421-428.

Kesseler E. y Knapen E.G. (2006). Towards human-centre design: Two case studies, The Journal of Systems and Software, Elsevier Science.
Lee, J. (2006). Chapter 60: Human factors and ergonomics in automation design, en Handbook of Human Factors and Ergonomics, Editado por Gavriel Salvendy, 1570-1596.
Maldonado, A. (2009). Ergonomic Evaluation Model for the Planning and Selection of Advanced Manufacturing Technology. Ph. D. Thesis (In Spanish). Technological Institute of Juarez, Mexico.
Maldonado, A. Sánchez, J., Noriega S., Díaz, J.J., García-Alcaraz, J., Vidal L., (2009). A Hierarchical Fuzzy Axiomatic Design Survey for Ergonomic Compatibility Evaluation of Advanced Manufacturing Technology. Proceedings of the XXIst. Annual International Occupational Safety and Ergonomics Conference, Dallas-Texas, 270-277.
Maldonado, A., Noriega S., Díaz, J.J., Sánchez, J., García J., De la Riva, J. (2010).International Journal of Industrial Engineering, Special Issue.
Majchrzak, A. (1988). The Human Side of Factory Automation, Jossey-Bass, San Francisco, Estados Unidos de America.
Masterson, L. (1987). Interaction between man and robots with some emphasis on "intelligent" robots, in Occupational Health and Safety in Automation and Robotics, K. Noro, Ed., Taylor & Rrancis, Londres, 143-150.
Mital Anil, Pennathur Arunkumar. (2004). Advanced technologies and humans in manufacturing workplaces: an interdependent relationship, 33, pgs. 295-313
Moray, N. (1986). Monitoring behavior and supervisory control, en K.R. Boff, L. Kaufmann y J. P. Thomas (eds), Handbook of perception and human performance: Volumen II: Cognitive processes and performance, , John Wiley and Sons, New York, pgs. 40-1,40-51.
Nicolaisen. P. (1985). Occupational safety and industrial robots-present stage of discussion within the tripartite Group on robotic safety, en Robot Technology and Applications,-Proceedings of the 1st Robotics Europe Conference, Brussels June 27-28, 1984, K. Rathmill, P. MacConaill, S. O'Leary, and J. Brown, Eds., Springer-Verlag, Berlin, pgs. 74-89.
Oxenburg, M. (1991). Increasing Productivity and Profit through Health and Safety, CCH International, Australia, pg.309.
Rao, V. (2007). Decision Making in the Manufacturing Environment. *Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods*. Springer, London, United Kingdom.

Ramachandran, V., Naadmuthu, G. (1989). Human factoring a robotic workplace, en Advances in Industrial Ergonomics and Safety I, pgs. 931-937.
Reason, J. (1990), Human Error, Cambridge University Press, New York.
Säften, K., et. al. (2007). The content and process of automation strategies, International Journal of Production Economics.
Sarter, N.B. y Woods, D. D. (1995). How in the world did we ever get into that mode? Mode error and awareness in supervisory control, Human Factors, Vol. 37, pgs.5-19.
Saraph, J.V,& Sebastian, R.J. (1992). Human resource strategies for effective introduction of advanced manufacturing practices (AMT). Production and Inventory Management Journal, 33 (1), 64-70.

Siemieniuch C.E. y Sinclair M.A. (1995). Information technology and global developments in manufacturing: The implications for human factors input, International Journal of Industrial Ergonomics, 16, pgs. 245-262.
Sugimoto, N. (1987). Subjects and problems of robot safety technology, en Occupational Safety and Health in Automation and Robotics, K. Noro, Ed. Taylor & Francis, Londres, pg.175.
Sugimoto, N., and Kawaguchi, K. (1985). Fault-tree analysis of hazards created by robots, en Robot Safety, M. C. Bonney and Y.F. Yong, Eds, Spreinger-Verlag, KFS, Berlin, pgs.83-98.
Susman, G.I. y Dean, J. W. (1992). Development of a model for predicting design for manufacturability effectiveness, en Susman, G. I. (Ed.) Integrating Design and Manufacturing for Competitive Advantage, Oxford University Press, Oxford, England, pgs. 207-227
Talluri S. y Yoon K. P. (2000). A cone-ratio DEA approach for AMT justification, International Journal of pProduction Economics, Elsevier, Science.
Vicente, K. (1999). Cognitive work analysis, towards safe, productive and healthy computer-based work, Lawrence Erlbaum Associates, Londres.
Wiener, E. L y Curry, R. E. en E. L. Wiener y D. C. Ángel (eds). (1980). Human factors in aviation (San Diego, CA: Academia Press), pgs. 433-459.
Wilson, J.R. Koubek, R.J. y Salvendy G., Sharif J., Karwowski W. (1994). Human Factors in advanced manufacturing: a Review and reappraisal, en Organization and Management of Advanced Manufacturing, Karwowski W. y Salvendy G. Eds. John Wiley & Sons, Inc. Estados Unidos de América.
Wobbe, W. (1990). Science, technology, and society towards the 21st.Century: European Choice, Economic Review, 39.
Wobbe, W. y Charles T. (1994). Human roles in advanced manufacturing technology, en Organization and Management of Advanced Manufacturing, Karwowski W. y Salvendy G. eds., John Wiley & Sons, Inc. pgs.62- 67.
Zimmolong, B. y Duda, L. Human error reduction strategies in advanced manufacturing systems, en Human-robot Interation, M. Rahimi and W. Karwowski, Eds., Taylor & Francis, Londres. pgs. . 242-285.