

ISSN 1979-0686

Journal of
Logistics and
Supply Chain Management

Volume 1, Number 2, June 2008

Published by:

DEPARTMENT OF INDUSTRIAL ENGINEERING, UNIVERSITY OF SURABAYA
and
ASOSIASI LOGISTIK INDONESIA

JLSCM

Vol. 1

No. 2

Pp. 61-122

Surabaya
June. 2008

ISSN 1979-0686

Journal of **Logistics and** **Supply Chain Management**

ISSN 1979-0686

Journal of Logistics and Supply Chain Management (JLSCM) is published by Department of Industrial Engineering, Faculty of Engineering, University of Surabaya in coordination with Asosiasi Logistik Indonesia.

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JLSCM is published three times a year on February, June, and October. The first volume was published on February 2008.

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Incorporating Ergonomics into Supply Chain Systems

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Abstract

The paper proposes and discusses the theoretical concepts of relevance to ergonomics which is mostly macro-ergonomics in the supply chain systems. The macro-ergonomics which is known as sociotechnical system tries to involve its role into today's biggest issue in manufacturing global management which is called the supply chain management. The supply chain management has a close relationship with macro-ergonomics since both concern a system of organization, people, technology, information and other resources. Some case studies are discussed and summarized in this paper. In addition, a conceptual model of ergonomics supply chain is also proposed. Strategically, this work will help to broaden understanding of importance of ergonomics to boost supply chain performance drivers in order to gain efficiency and responsiveness in meeting company's competitive strategy.

Keywords: ergonomics, macro-ergonomics, sociotechnical, supply chain management, performance drivers

1. Introduction

The purpose of this paper is to discuss some theoretical concepts of relevance to ergonomics in the domain of manufacturing processes to enhance the effectiveness and efficiency of the supply chain systems. At the beginning, ergonomics has been regarded as a discipline focusing on how to design comfortable chair to the users, to design convenient workstations, or other work system which is called human and machine interface. Substantially, this view has been already known as micro-ergonomics; the basic discipline of ergonomics. However, few years later, ergonomics has shifted and become a discipline in meeting consumer's needs. In recent years, the changes of focus of ergonomics have been increasing significantly. This metamorphosis was proven by the milestones of ergonomics. In the 50's ergonomics was known as military ergonomics, 60's as industrial ergonomics, 70's as customer and service ergonomics, 80's as computer ergonomics, and at the beginning of 90's and year 2000 ergonomics is famous as cognitive and macro-ergonomics [10].

According to the increased changes in technology and innovation, the discipline of ergonomics has become more complicated. More recently, the application of ergonomics has been too wide. It is a must for ergonomists to take parts in solving today's complicated problems. Therefore, it is much more important to look into deeper and broader the application of ergonomics, which is known as macro-ergonomics. The context of macro-ergonomics is not only focusing on human and machine itself, but also how the interactions between human and their sociotechnical issues. In other words, the macro-ergonomics will be more dealing with complicated environmental issues. With respect to the supply chain systems, macro-ergonomics should be regarded as one of contributors to the significance of supply chain performances. It is because there will be roles of humans/operators, procedures, machines, information and other components in a particular supply chain system. A brief explanation of components of supply chain system is provided in Section 2. In other words, supply chain is regarded as socio-technical system since it is very complex organization where involving the interaction between people and technology. Thus, it is applicably needed how to involve ergonomics in the supply chain system such as how to design a comfortable work station, how to interact between operators comfortably, how to manage a good flow of information, how to achieve high productivity with safety consideration etc in order to achieve high level of performance in the supply chain system. However, there is not a formal approach or methodology to incorporate ergonomics (micro-ergonomics and macro-ergonomics) in the supply chain system. Therefore, to fill in this niche, this paper proposes a

conceptual model of ergonomics supply chain with some case studies, to give some enlightenments of the important role of ergonomics in today's complex supply chain problems.

2. Supply Chain Management

In today's fast global changing markets, the introduction of products with shorter life cycles, fast delivery, and the heightened expectations of customers have forced business enterprises to invest in, and focus attention on, their supply chains [8].

The supply chain includes all functions involved in filling a customer request in certain organization. These functions are including new product development, marketing, operations, distribution, finance, and customer service [1]. In addition, a supply chain is also called a dynamic activity and involves the constant flow of information, product, and funds between different stages.

In general, the goal of every supply chain is to optimize the overall value generated which is the difference or gap between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request [1]. It is hoped that the difference will bring a positive profit or benefit to be shared across all chain stages.

Successful supply chain management needs several important decisions related to the flow of information, product, and funds. These decisions will be broadening into 3 phases which are supply chain strategy, supply chain planning and supply chain operation [1]. In the first phase, supply chain strategy, it is including how to decide the location and capacities of production and warehousing facilities, products to be manufactured or stored at various locations, modes of transportation to be made, and also type of information system to be utilized. The second phase which is supply chain planning, it includes which markets will be supplied, buildup inventories, the subcontracting of manufacturing, the replenishment and inventories to be followed and finally into the timing and size of marketing promotions. The final stage, supply chain operation, mainly it includes implementation the operating policies in the best possible manner in the fixed supply chain configuration and defined planning policies.

In order to improve the supply chain performance in terms of responsiveness and efficiency in meeting the needs of the company's competitive strategy, it is needed to investigate and evaluate four drivers of supply chain: inventory, transportation, facilities, and information. The supply chain strategy should determine how the supply chain should perform with respect to efficiency and responsiveness. Wal-Mart as a good example of effective and efficient supply chain implementation uses each supply chain driver to achieve the right balance between responsiveness and efficiency so that its competitive strategy and supply chain strategy are in harmony. This framework for supply chain decision making [1] is shown if figure 1.

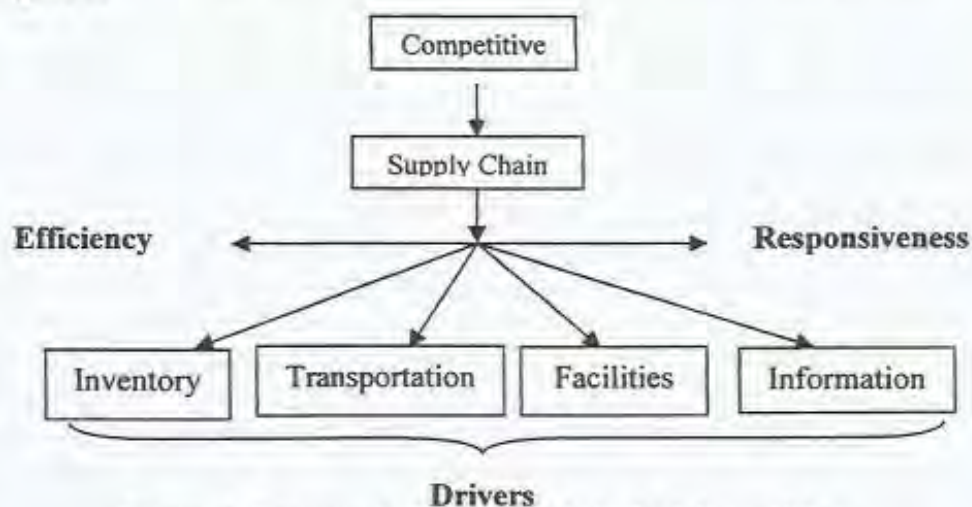


Figure 1. Framework for supply chain decision making

Inventory is a sensitive and important supply chain driver since fluctuate amount of inventory could make some changes in the supply chain's efficiency and responsiveness. Transportation has much combination of modes and routes with some specific performance characteristics. How to determine and decide the production site, production line, warehouse, and storage sites will be discussed and examined in the facilities performance driver. The last one is information; it is potentially the biggest performance driver in the supply chain since it directly influences each of other drivers.

It is not enough that the supply chain should comprise world-class companies; they must also be bound together by communication links that enable the whole chain to respond with sufficient speed and flexibility to meet the steadily increasing competitive challenge in the marketplace. Furthermore, there is a requirement for self-improvement, of both the company and its supply chains [4]. It means that how to bring new products to the marketplace as quickly as possible with fairly cheap price should be highlighted. Commercial products are a compromise between conflicting goals. The most important conflict is that between the customer's performance criteria, the price that customers will pay, and the price of competitive products. Hence, how to achieve the efficient and effectiveness of supply chain systems with regard to its performance drivers is a challenge should be solved.

3. Ergonomics

Commonly, ergonomics is one of disciplines concerned with the understanding of interactions among human and other elements of a system such as machines, equipment, procedures etc. It aims to optimize human well-being, safety, productivity, efficiency and effectiveness. It also contributes to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with and fit the needs, abilities and limitations of human being (IEA, 2000). Several aspects that should be considered in the ergonomics areas are safety, convenience, comfort, ease of use, productivity/performance, and aesthetics. The International Ergonomics Association (IEA) divides ergonomics broadly into three main domains: physical ergonomics, cognitive ergonomics and organizational ergonomics which is referred to macro-ergonomics.

Ergonomics is associated with a human-centered design or manufacture. The concept of human-centered manufacturing focuses on five basic principles of work design [5], those are, (1) retention and enhancement of existing levels, (2) extension of operator choice and control (humans control the technology, not vice versa), (3) minimal subdivision of work (unites planning, execution, and monitoring), (4) maximization of human operator knowledge of the whole production process (encourages social communication and interaction), and (5) consideration of ergonomic factors (layout of equipment, design of keyboards, software, production facility, etc.).

4. Macro-ergonomics

One of the domains in the ergonomics is organizational ergonomics which is also familiarly called as macro-ergonomics. It is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes (IEA, 2000). Relevant topics include communication, the allocation of human resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, teleport, and quality management. Macro-ergonomics is concerned with factors in the technological subsystem, personnel subsystem, external environment, and their interactions as they impact on work system design. Its goal is to optimize the work system's design in terms of its sociotechnical system characteristics, and then carry those characteristics down through to the design of individual tasks and human-machine interfaces to obtain a fully harmonized work system.

Based on its survey of human factors internationally, the Strategic Planning Committee of the Human Factors and Ergonomics Society (HFES) identified the unique technology of human factors/ergonomics (HF/E) as human-system interface technology. It is including the interface between

the people portion of systems and the other sociotechnical system components. Sociotechnical system component is known as macro-ergonomics which is a perspective, a methodology, and a recognized sub discipline of ergonomics/human factors [6].

There are some criteria for an effective work system design approach [6] as the following: joint design, humanized task approach and integrate the organization's sociotechnical characteristics into the design. In joint design, the design approach should be human centered which should require design of the personnel subsystem jointly with the technological subsystem. The second one which is humanized task approach, the function and task allocation process first should consider whether there is a need for a human to perform a given function or task before making the allocation to humans or machines. In the last approach, the integration of organization's sociotechnical characteristics into the design, should systematically evaluate the organization's key sociotechnical system characteristics, and then integrate them into the work system's design.

4.1 *Ergonomics in Organizations*

The concept of ergonomics in organizations considers the concept of participative ergonomics, where people from many areas including commercial, logistics or supply chains, operation, etc will work in conjunction with ergonomists in accomplishing their projects. This is the big issue of how to arrange and place the right people to the right place in certain organization.

4.2 *Ergonomics in Supply Chain System*

Nowadays, the role of ergonomics is approaching to the closed relationship between employees and their environment in complex aspects [7]. Ergonomics is not only concerned with human, but also a system as a whole. Essentially, ergonomics is divided by two main branches, those are, micro-ergonomics and macro-ergonomics. Micro-ergonomics is regarded as a view of ergonomics of how to involve man, machine, method, material and all components of a particular system separately. Whereas, macro-ergonomics is concerned with a broad view of ergonomics which is so called socio-technical system. Macro-ergonomics as one of the extended ergonomics deals with cultures, environments, and organizations in a broad system. Since supply chain management is regarded as a system of organization, there will be a closer relationship between macro-ergonomics and supply chain management. Both micro-ergonomics and macro-ergonomics approach will highly support and enhance the performance of supply chain in enterprises. The concern of how to maintain comfortable work station, flow of material, safety, teamwork and other ergonomic issues are the focus of ergonomics in enhancing the efficiency of supply chain system. Lack of ergonomics consideration could solely affect the key roles of supply chain function such as the flow of materials or products, safety, and information which results in loss of profit (fund). As a result, it is likely to decrease the supply chain performance in the end.

Organizational and related human issues, which are the focus of the commonly ergonomics and macro-ergonomics discipline as well, are critical to the success of technology, which is greatly dependent on the nontechnical characteristics of a corporation. Ergonomics can play an important role in supporting the material and information flow management in particular enterprises. Human resource utilization as the most important key concerns of ergonomics is considered essential for assuring efficient manufacturing and high quality products [8]. In today's competitive business world, employees are expected to work faster, harder and with more qualified result to meet customers' needs. Besides of the material flow management, ergonomics should allow employees to function at their highest level of productivity, quality and efficiency with lowest risks or ideally without any risks. It means that there should be no occupational risks of workers' compensation claims, no lost working time, and increasing the productivity level. It is because the biggest issue of ergonomics is how to maintain the employees or operators in appropriate way when they are working either in manufacturing areas or other organization levels in safest way since human is priceless. In addition, all the

workstations available should fit to the body dimensions of operators (anthropometry) so that they can work safely, comfortably and more productive. Thus, the lower rate of fatigue or accidents should be reduced. Hence, the issue of human resource management in terms of safety and productivity will be an ultimate role in achieving high level of supply chain performance.

Intuitively, ergonomics can also be viewed as the principal engineering discipline involved in the physical planning for materials transportation: from the suppliers to points of storage or use; for the materials handling in receiving and shipping and between processing operations; and for material storage (purchased, work in progress and finished goods). The engineering ergonomist may have to work with suppliers, providing specifications to minimize injuries, lost work time and inefficiencies to the human system, as well as specifications related to the materials management. Other objectives for the procurement, transportation, production planning and control, warehousing and information systems must also be included in the ergonomics process [9]. In other words, ergonomics also should be considered as the important factor in those combined engineering principles which are also called as value chain.

Supply chain is regarded as a value system which includes the value chains of a firm's supplier, the firm itself, the firm's distribution channels, and the firm's buyers [10]. The ergonomic assessment should also be understood and applied better for vendors, suppliers, and all components of the value chain in achieving high level of supply chain performance. The value chain consists of primary activities and support activities. Primary activities include: inbound logistics, operations, outbound logistics, marketing and sales, and services. The other one which is support activities is including administrative infrastructure management, human resource management, information technology, and procurement. The structure of value chain [10] is shown in figure 2.

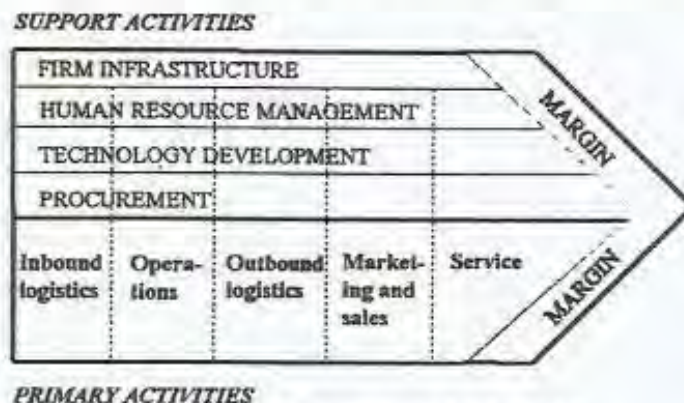


Figure 2. Porter's value chain model

Inbound logistics includes receiving, storing, inventory control and transportation scheduling. Inbound logistic is the most critical stage in manufacturing supply chain [11]. The operations include machining, packaging, assembly, equipment maintenance, testing and all other value-creating activities that transform the inputs into the final product. The outbound logistics is the activities to get the finished product to the customers including warehousing, order fulfillment, transportation, and distribution management. Marketing and sales include channel selection, advertising, promotion, selling, pricing, and retail management. The last one of primary activities, service, includes customer support, repair services, installation, training, spare parts management, and upgrading. The main purpose of researches provided in this paper is to obtain maximal values in primary activities rather than those of support activities.

Macro-ergonomics supports variety of value chain [9]. In the production process, the ergonomic assessment of time and motion study should consider the limitation of employees. It is important to choose the correct and fitted equipment being used. How to manage and maintain the stresses of employees should be taken into account while company using the new high technology such as cellular

manufacturing. In terms of transportation aspect, the role of ergonomics could take a part, for example, the selection of good pallet and container should be taken into consideration. Wooden pallet should be avoided as it is potential to cause injuries although it is less expensive than plastic pallet. The ergonomic specification, such as the anthropometric consideration of pallet dimension, will reduce loading and unloading time that can result in delivery time and waste. How to design a comfortable seat for driver in the truck should be an important attention since it will reduce driver's fatigue and also certain injuries. Choosing trucks with automatic transmission perhaps could be one solution to increase productivity. The next consideration is that how the ergonomics plays an important role in the material handling and storage. The lifting, lowering, pushing and pulling are some activities which potentially cause injuries. It is considered to avoid employees lift material from the floor in order to reduce back injuries; therefore the minimum lift is maybe as high as the 5th percentile of female hip height. In selecting lift trucks, it is considered to make sure a good driver visibility and plain flooring. Companies should ensure good and safe conveyors that make sure the materials cannot fall off the conveyors and avoid sharp angles in the conveyor setup. In warehousing, it is useful to avoid storing material too high and too low since it is uncomfortable to employees. In storing material, weight is important issue. The principal of Recommended Weight Limit (RWL) by NIOSH [13] should be highlighted. In addition, the clear information and material flow are also highlighted since these will give a clear understanding and promote less stress to all employees. Thus, the macro-ergonomics promotes the synergy among those all ergonomic considerations in the value chain. The role of micro-ergonomics and macro-ergonomics in the supply chain system is shown in the Section 6 Proposed ergonomic supply chain conceptual model.

This paper shows some case studies which describe the relevance of ergonomics (mostly macro-ergonomics) to the value chain in some manufacturing industries.

5. Case study

There are three summarized case studies provided in order to show a better understanding of the role of ergonomics in supporting supply chain systems. Despite these are not holistic application, but it is highly important to shed some light to the importance of ergonomics in supporting the performance of supply chain. They are as the following:

5.1. *The Application of Ergonomics to Improve the Quality of Life at Work in the Food Sector Distribution Centers*

The application of concept of participative ergonomics, where people from the commercial, logistics, operation, occupational health areas worked in conjunction with the industrial designers, ergonomists who methodologically led the project [13]. The results of their project show a description of ergonomic systems that will enable specific work stations to be designed and a primary prevention strategy in the field of health, aimed at reducing occupational risks, improving the quality of life at work in the food sector company distributor centers. Their work discusses how to handle high incidental variability due to a high risk of muscular-skeletal disorders in workers at the company's Regional Distribution Centers (RDC). Some variables considered in the diagnosis of the RDC's are shown in the table 1.

The table 1 shows that the elements of the ergonomic system (human being, object-machines and physical spaces) and their interactions were described and analyzed, considering relationships with the work organization variables (macro-ergonomics) in which supply chain involved. In other words, it is said that this work proposes that macro-ergonomics and micro-ergonomics variables be integrated. It seems that complexity and simplicity are united. Mostly, the issues of ergonomics are involved in primary activities of inbound logistics, operation and outbound logistics in value chain of RDC.

Table 1. Variables considered in the diagnosis of the RDCs current situation [13]

Component	<i>Micro ergonomic variables</i>	Work organization—broader technological variables (<i>macro-ergonomics</i>)
Human being	Basic anthropometric measurements, age, weight, height, seniority, relevant medical records, education and training.	Working rules (simultaneous, parallel, successive), coordination, working teams, shifts.
Objects/machines	Classification in furniture, tools, machines, health and safety care equipment. General structure of the objects where interaction problems were observed	Technological state (traditional or stable, in change process or new technology) and technological level (manual, mechanized, automated).
Physical space (physical environment)	Work station indicating performance areas, circulation, mobility, routes. Environmental conditions including chemical, physical or biological conditions that can affect the activity. Safety conditions including exits, areas demarcation, safety signs, emergency equipment location.	Functional location of workstations. Products, materials, persons and waste flows, possible interferences between workstations.
Interactions between elements	Associated risk factors, work cycles, strength and movement requirements.	Working day (weekly and monthly arrangement) breaks, state of mind situation that affects work performance.

5.2. The Application of Ergonomics to Improve Facilities by Controlling Manual Handling Risks in a Soft Drink Distribution Centre

This case study was taking a case in a soft drinks distribution centre [14]. Methods used included semi-structured interviews, document analysis, analysis of training, Ovako Working posture Analyzing System (OWAS) postural analysis and use of the National Institute of Occupational Safety and Health (NIOSH) equation. OWAS [15] gives a simple observational method, providing categorization of working postures into those relating to the back, upper and lower limbs. NIOSH equation [12] was used to determine level of risks associated with manual materials handling (MMH) tasks. The calculation considers factors including horizontal and vertical distances, frequency of lifting, asymmetry and coupling (grip) to determine the Recommended Weight Limit (RWL) for a particular set of circumstances. A "load constant" (LC) of 23 kg (about 51 lb) was established by NIOSH as a load under ideal conditions, is safe for 75% of females and 90% of males.

Warehouse operators and delivery drivers which are very important supply chain performance drivers were observed and studied using OWAS and NIOSH equation. The result was that manual handling risks were found in both warehouse and delivery areas, being regarded as "excessive" using the NIOSH equation. It revealed a superficial risk assessment and lacking awareness of the wider factors involved [12].

In order to reduce the risks caused by that system, it is considered to study for organizational or cultural changes, ergonomic and economical motion of posture, and use of ergonomic appropriate equipment or material handling facilities. The issues of ergonomics are involved in primary activities of inbound logistics (lifting activities in storing materials), operations (appropriate designed equipment) and outbound logistics (lifting activities in warehouse). The low risk of injuries due to appropriate weight limit by NIOSH equation will promote high employees' productivity. Hence, once the problem of risks is reduced, the right flow of products in the warehouse and delivery areas should be easily performed. As a result, these will affect the enhancement of supply chain performance. Therefore, the importance of ergonomics in the supply chain systems should be taken into consideration.

5.3. *The Application of Ergonomics in the Information Flows and Management of Distributed Knowledge in the Manufacturing Supply Chain*

This case study discusses some of the relevance of ergonomics issues involved in simultaneous engineering from the perspective of supply chains [4]. In the simultaneous engineering approach, a good design and an efficient design process are critical competence for any manufacturer's product introduction process. Achieving the aims of simultaneous engineering (which includes those of design for manufacturability) requires an optimum combination of people, technical knowledge, and technology.

There are two main functions which supply chains in manufacturing perform. The first of these is to supply goods to the end-customer as efficiently as possible. Efficiency here means on-time supply of the right goods at lowest cost. The planning of manufacturing and the control of logistics are key issues here. The second one is to introduce new products which address the end-customers' needs to the market at the right time and at a 'value for money' cost. This includes the design and development of both new products, and the processes necessary for the life cycles of those products.

The ergonomic issues in this supply chain system are capturing relevant data, delays and synchronicity of data. In the context of simultaneous engineering within supply chains, then there are four requirements which must be met. These are as follows:

- The means to condense data into meaningful, readily available information
- The means for the presentation of information to its human users in useful and usable ways
- The means to allow humans to manipulate the information to assist in reaching decisions
- The means to communicate information along the supply chain to solve problems

In short, there are two main activities in the information flows and management of distributed knowledge: firstly, the ability to generate, manage, and transfer relevant information along the supply chain as required. Secondly, the ability to form teams who possess the right knowledge and support tools, and are equipped with responsibilities, and who can interact with other teams in a continuously work. Ergonomics has a major role to link these two threads. It will ensure that companies have the right people in the right jobs, with the right tools to secure their own and the company's future [4].

Hence, the role of ergonomics is to fit the task to the human, not to fit the human to the task. The task includes information, jobs, facilities and other equipment. As a result, an ergonomic flow of information as one of the framework for supply chain decision making could be achieved. It means that the supply chain performance should have been improved.

6. **Proposed ergonomic supply chain conceptual model**

A conceptual model of ergonomic supply chain is proposed to describe a more detailed relationship between ergonomics (micro-ergonomics and macro-ergonomics) and supply chain value (value chain). Ideas that have been done before and discussed above are regarded as useful insights to build this conceptual model. It is adopted from Porter's value chain model with several additional variables in order to make it more applicable for today's complexity in ergonomics area. The current condition and future challenge of manufacturing in terms of macro-ergonomics and micro-ergonomics [16] is also examined. The proposed model is shown in appendix A.

Currently the model is focusing on the primary activities of value chain, i.e. inbound logistics, operations, outbound logistics, marketing and sales, and services. The ergonomics which is consisting of micro-ergonomics and macro-ergonomics are not separated parts in supporting the company value chain. In each part of the primary activity, e.g. inbound logistics, the role of micro ergonomics should be taken into consideration. The roles of man, machine, method, material, and environment as determinants of the micro-ergonomics should be carried out. For example, in the case study of food distribution centers (please refer to section 5.1), the basic anthropometric measurements for operators, and ergonomic work station design and its environmental condition are some of main concerns of ergonomics in achieving good logistics performance. Lack of these ergonomics considerations may

solely affect the flow of materials or products, information, and funds which are the key roles of logistic systems. Hence, micro-ergonomics consideration is one of important parts that should not be vanished in the supply chain systems. In addition, how the interaction of workforces, workstations, working rules, and other micro-ergonomics determinants either within or among primary activities are becoming a big concern as well; it is how the macro-ergonomics taking a place. The macro-ergonomics can play an important role in supporting the material and information flow management and their interaction in the company. Regarding the efficiency of supply chain, ergonomics can also be viewed as the principal engineering discipline involved in the physical planning for materials transportation: from the suppliers to points of storage or use; for the materials handling in receiving and shipping and between processing operations; and for material storage (purchased, work in progress and finished goods). Starting from inbound logistics in the value chain, the engineering ergonomist may have to work with suppliers, providing specifications to minimize injuries, lost work time and inefficiencies to the human system, as well as specifications related to the materials management (please refer to section 4.2 for details). It is hoped that the model should give a deeper understanding how the relationship among micro-ergonomics, macro-ergonomics and value chain in the supply chain systems.

7. Conclusion

This study identifies the relationship between ergonomics and supply chain systems in manufacturing industries. Lack of ergonomic consideration in the supply chain drivers could solely affect the flows of materials or products, information, and funds which are the key roles of supply chain function. Some case studies are discussed in order to highlight the important role of ergonomics in supporting supply chain performance. The relationships between macro-ergonomics and supply chain system are also addressed. It is worth highlighting the determinants of ergonomics such as the physical capabilities of employees, safety, the task requirements, the equipment/tools requirements, policies or procedures in working systems should be taken into account in each parts of the value chain of companies. Those ergonomics factors support and promote the performance of supply chain system; those are shown in the case studies. For general purpose and guideline, a conceptual model of ergonomics supply chain is proposed. This study reaches the conclusion that further effort may be required to ensure the involvement of ergonomics in each stage of either primary or support activities of value chain as one of supporting systems for excellent supply chain performance.

Acknowledgements

This paper would not have been possible without the sharing support given and inspired by author's colleagues in Department of Industrial Engineering University of Surabaya who are mainly focusing their researches on logistics and ergonomics. The author would like to thank a lot especially to R.M. Suryani and A. Santoso as their work and idea have given lots of insights to the work of this paper. Finally, the author also would like to thank the two anonymous reviewers for the comments that improved the clarity and direction of this proposed paper.

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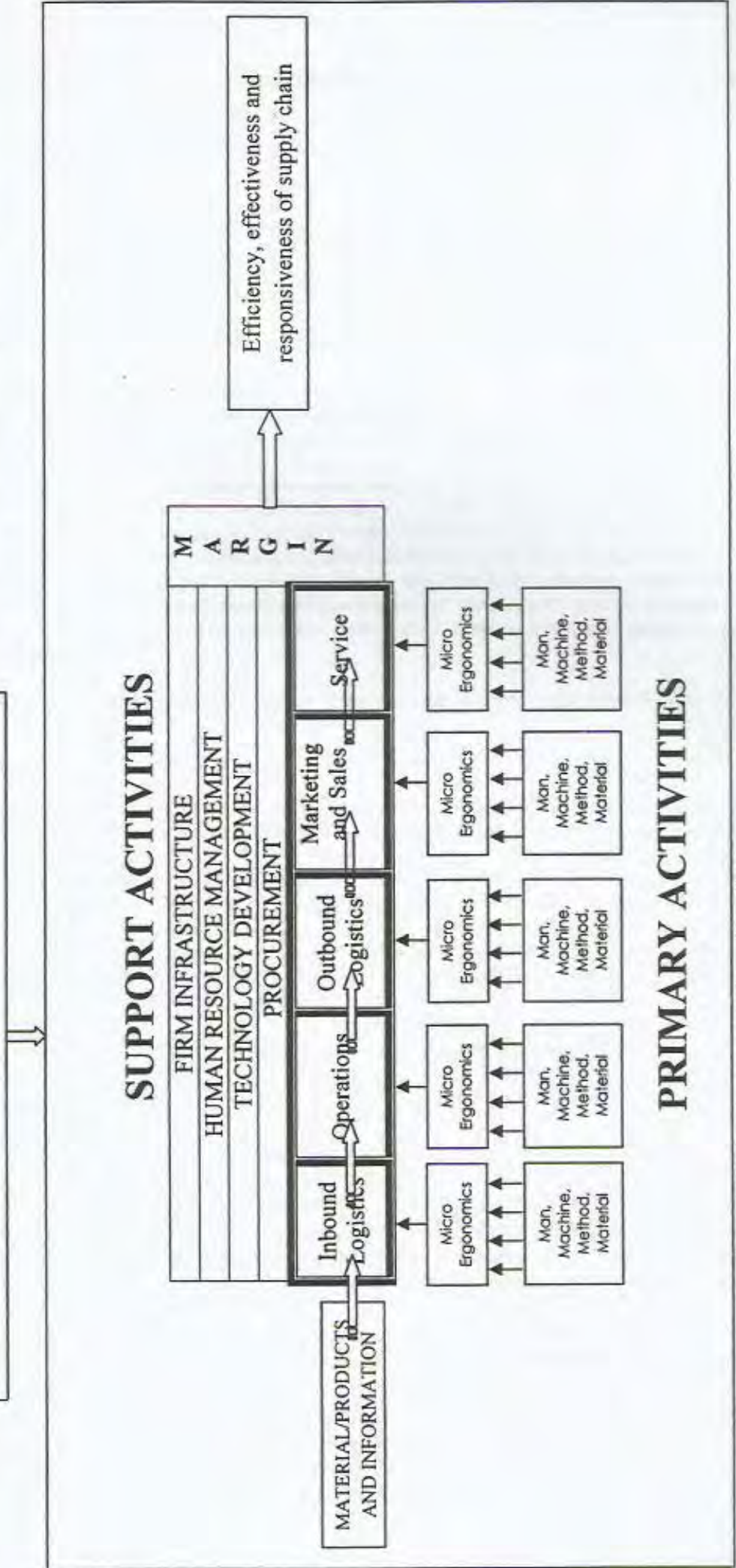
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APPENDIX A

Proposed ergonomic supply chain conceptual model

MACRO ERGONOMICS: socio-technical systems **SUPPLY CHAIN: systems of organizations (complex systems)**



Note: is material/products and information flow