Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-1 (2017) 13958–13963

Preliminary cognitive model of a semi-mechanized picking operation

Martha Caro*. Leonardo Quintana**
Juan Castillo***

* Industrial Engineering Department, Pontificia Universidad Javeriana, Bogota, Colombia
(Tel: 057-1-3208320; e-mail: mpcaro@ javeriana.edu.co).
** Industrial Engineering Department, Pontificia Universidad Javeriana, Bogota, Colombia
(Tel: 057-1-3208320; e-mail: lquin@ javeriana.edu.co)
*** School of Medicine and Health Sciences, Universidad del Rosario,
Bogota, Colombia, (Tel: 571+2970200; e-mail: juan.castillom@urosario.edu

Abstract: The current paper develops a pioneering approach to the human factors of picking operations, which are addressed from a cognitive perspective. The model is established through a qualitative methodology, which based on several theories, is articulated and applied to the real situation of a dry foods company. The results combine the cognitive architecture of the operation and its relations with logistic factors to decrease the amount of human error and thus increase the service level. This model provided evidence for three logistic factors, namely, the picking zone type, the order difficulty level and the experience level; furthermore, from the cognitive perspective, attention and memory.

Keywords: **Cognitive systems, Human Factors, Human error, Ergonomics, Picking Operation, Qualitative analysis**

1. INTRODUCTION

COGNITIVE ERGONOMICS IN SUPPLY CHAINS

Cognitive Ergonomics in supply chains has been studied from many different points of view. For example, (Resnick, 2008) identified training techniques such as task analysis—which is used for improving decision-making in global chains—through sophisticated metacognition. Specifically regarding picking operations, a study by Goomas & Yeow (2010) analyzed the cognitive aspects of a voice picking system in order to improve workers' welfare and attain better quality through error reduction.

These studies concluded that human factors, apart from physical aspects, should be kept in mind to improve both welfare and performance. According to Kanji & Wong (1999), cited in (Arzu Akyuz & Erman Erkan, 2010), human and organizational aspects should be studied by measuring individual performance in terms of the percentage of errors, paying special attention to work quality. In addition, human factors have been involved in supply chain studies through mathematical optimization models (Khan, Jaber, & Guiffrida, 2012) implying that variables, such as inspection or operation errors and quality learning level, have elevated cost impacts (Raouf, Jain, & Sathe, 1983; Jaber & Bonney, 2011). However, these mathematical models have not been based on real operation conditions but only on simulations. From the perspective of information systems design, (Swan, 2007) undertook an experimental study for the validation of the business process management (BPM) systems to identify cognitive resources applied by the users to understand the software.

Furthermore, the performance of human factors within the supply chains has been measured in terms of quality (i.e., error) (Goomas & Yeow, 2010; Arzu Akyuz & Erman Erkan, 2010 ; Khan et al., 2012); time (Kuhlang, Edtmayr, & Sihn, 2011; Resnick, 2008); and even learning (Zink & Seibert, 2009 ; Khan et al., 2012).

PICKING OPERATION

Picking represents approximately 55% of supply chain operational costs (Tompkins, White, Bozer, & Tanchoco, 2010), cited in (Burinskiene, 2010), since it is the most laborious and time consuming activity at a distribution center (Burinskiene, 2010; Grosse, Glock, Jaber, & Neumann W Pattrick, 2014). Picking efficiency is measured in terms of speed (De Koster, Le-Duc, & Roodbergen, 2007), cited in (Burinskiene, 2010) and accuracy (whether the collected items match the picking order). In other words, picking is significant not only for the labor cost it represents but also for the effect it has on the service level for the customer (Burinskiene, 2010).

Accuracy is currently considered to be a fundamental aspect of organizational success. In labor-intensive environments, accuracy has a direct relationship with picking human errors, which, in turn, are caused by the storage and picking methods, among other factors (Burinskiene, 2010). The picking operation, which makes use of tools, such as paper lists, scanners, lasers and voice technology, can be carried out in different ways, such as picking from multiple positions or doing multiple picks at each stop. (Gu, Goetschalckx, & McGinnis, 2010) say that there is a direct connection between the service level and picking, especially regarding the picker's travel speed and the product search through the warehouse.

In turn, (Grosse et al., 2014) made an exhaustive literature review to identify those studies that incorporated human factors in the planning of picking operations, with the further

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.2219

goal of identifying those that might shelter research perspectives, by means of an adequate conceptual framework specifically developed for this purpose. In turn, worker features are considered to be a determinant in operation outputs (Powell & Johnson, 1980 ; Karwowski, 2006), cited in (Grosse et al., 2014).

The conceptual framework provided by Grosse et al. (2014) identifies three macro analytical perspectives: (i) Modeling and planning, which comprise of layout outlining, warehouse assignment, routing and work organization. Its optimization has been studied through mathematical modeling (Lin & Lu, 1999; Wong & Wong, 2007; Khan et al., 2012; Pan & Wu, 2009); (ii) System outputs, which cover performance, quality and worker health; and finally, (iii) Human factors, namely, mental, perceptual, physical and psychosocial. For their part, Grosse et al. (2014) state that picking systems have been studied with two main goals: the improvement of effectiveness and efficiency and the development of better conditions for workers (Sanders & McCormick, 1987), cited in (Grosse et al., 2014). The latter contend that the improvement of effectiveness and efficiency is directly related to error reduction and productivity enhancement. These approaches to the human factors in the picking operation facilitate focusing on its mental and perceptual aspects, which, in turn, constitute a new research domain featured by the encounter of cognitive elements and picking human errors. As to the mental aspects of picking, (Grosse et al., 2014) described a relationship between an elevated proportion of repetitive tasks, cognitive picking abilities, and workload.

Finally, picking systems are classified according to their labor demands (Logistics Simulation, cited in (Burinskiene, 2010). Therefore, there are manual, semi-mechanized and mechanized systems. Approximately 75% of all picking systems operate manually (Burinskiene, 2010). The intense labor requirements of these dominant picking systems make human factors outstandingly important (Grosse et al., 2014), more so because they determine the effectiveness and efficiency of the process.

Making up a lower fraction (7%), the semi-mechanized systems operate in three different ways: horizontal carousels, vertical carousels and stock pickers. Among them, variations such as the "pick to pass" system have lately gained momentum as a response to electronic commerce and the need to be time-competitive. (Pan & Wu, 2009) developed a Markov chain analysis of one of these systems to estimate the picker traveling distance to the picking zone. Finally, the scarcest system type is the totally mechanized one (2%).

COGNITIVE ELEMENTS IN PICKING OPERATIONS

The way the picker receives information and makes it useful is considered to be a key perceptual aspect of the operation (Brynzér, H. (1,2) & Johansson, 1995; Grosse et al., 2014) . One of these perceptual aspects is the picking list, which has not been studied in distribution centers. However, it has been analyzed in other manual operations requiring paper-picking lists with the purpose of reducing the information search time. (Grosse et al., 2014) identified design, content and distribution as important aspects of the information conveyed by a picking list. Design is related to font size, which influences the ease of reading and memorization. Other aspects are the color and spatial positions, which have been found to affect the search time (Bishu, Donohue, & Murphy, 1991).

Other picking system design perspectives allow for a larger influence of the technology. Such is the case of radiofrequency equipment linked to the Warehouse Management Systems involving barcodes, handhelds and scanners. Likewise, (Bishu et al., 1991) found that a shorter item code influenced the search time. In turn, (Weaver, Baumann, Starner, Iben, & Lawo, 2010; Brynzér, H. (1,2) & Johansson, 1995) included graphical layout information and highlighted product amounts in the picking order list, thus reducing the search time. According to a literature review by Grosse et al. (2014); Bishu, Donohue, & Murphy (1992) demonstrated that the reading order in shelves works better from left to right and from top to bottom; and (Gudehus & Kotzab, 2009) suggested the use of radiofrequency to facilitate information perception.

COGNITIVE MODEL OF A MANUAL PICKING OPERATION FROM THE AVAILABLE LITERATURE

Based on the available literature on the topic, the present work has developed a cognitive model of the manual picking operation. Two steps were analyzed: information identification and the actual product picking decision. Information identification is carried out through picking lists, wherein design (Bishu et al., 1991; Grosse et al., 2014), content (Bishu et al., 1991; Grosse et al., 2014) and distribution (Brynzér, H. (1,2) & Johansson, 1995; Weaver et al., 2010) are cognitive aspects influencing the speed and accuracy, as shown above. The product picking decision has been observed to comprise two sub-steps, namely, a global scan and a position location (Duncan, 1984; Julesz, 1975). These authors studied the performance of novice and expert operators as affected by aspects like position and color. In turn, (Bishu et al., 1991) conducted studies related to the shelf label orientation. In sum, the different studies available on the cognitive elements that influence picking have been developed in different domains, and although they have been used as a reference framework for the present research, they do not allow establishing a formal cognitive model for this operation. Nonetheless, among the most important goals of a picking system operations are its effectiveness and efficiency, which are measured by speed and accuracy, the latter being specifically, related to the percentage of picking errors. Information changes and warehouse positions have been found to influence quality in terms of error percentage (Brynzér, H. (1,2) & Johansson, 1995). Likewise, (Brynzér, H. (1,2) & Johansson, 1995) detected some causes of picking errors: (i) mixing of several components at a given location; (ii) interruptions to the operator; and (iii) similarities in the appearance of several elements that are located close to one another. In turn, Grosse & Glock (2013) found that the number of orders was inversely correlated to that of the number of errors; and (de Koster, Le-Duc, & Roodbergen, 2007) described that a clear route pattern reduces both the number of errors and the time for the search.

Finally, (Brynzér, H. (1,2) & Johansson, 1995) have described radiofrequency and barcodes as error reduction strategies. However, they do not guarantee error elimination because of the persistence of the human and system interaction. Exploratory studies on the human dimension of picking by Caro, Segura & Quintana (2014) had already identified a series of error types, their main causes and error classifications according to the (Reason, 1990) classification system and (Rasmussen, 1982) taxonomy (Fig. 1).

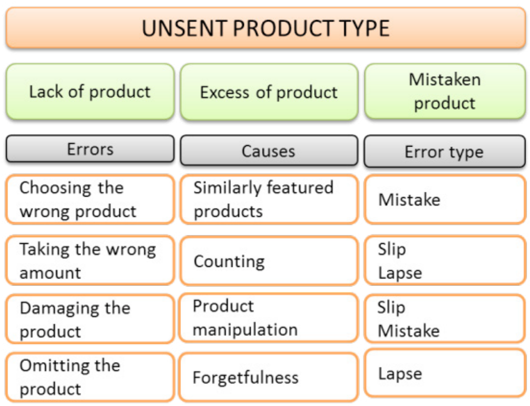

Fig. 1. Error sources of the picking operation

In summary, new research avenues on the cognitive perspective have emerged with the study of human factors in picking environments, such as the postal or automotive industries, resulting in conceptual frameworks that can be applied to areas that have not been addressed from this perspective. This is precisely the case of semi-mechanized picking operations in distribution centers. Therefore, the present work actually opens a new research line through the development of a cognitive model for the real semi-mechanized picking operation of a dry foods distribution center. The model intends to identify the elements that are likely to cause human error and decrease the level of service.

2. METHODOLOGY

The methodology used to develop this study is based on the concepts of distributed cognitive systems (Woods, 2003), cognitive analysis in dynamic situations (Hoc & Amalberti, 1999), and process tracing for the study of cognition outside the laboratory (Woods, 1993), all of which were used to design the information collection and analysis protocol (Fig. 2).

The protocol follows four phases. The first one corresponds to the field observation of the natural flow of the operation by means of ethnographic techniques. This step identifies the characteristics of the operation and the ideal conditions for recording the task through systematic videos. At this phase, it was possible to determine the analysis unit, which corresponds to each of the picking zones. Ten containers per picking zone were adequately labeled with information that allowed tracing the origin of the products the pickers had put in them (Woods, 1993). In the second phase, some videos were recorded to be analyzed during the third phase through a codification system designed according to theoretical guidelines by Hoc & Amalberti (1999). This codification protocol allowed for the identifying of cognitive architectures, which are made up of different cognitive activities and elements. In the fourth phase, a guided verbalization on the part of the operators is elicited and contrasted to the video, seeking to confirm in depth the mental processes underlying their performance. Furthermore, at this stage, it was possible to inquire into the likely error causes (Rasmussen, 1982). In summary, the current methodology provides two main results, namely, the cognitive model and the cognitive elements that might influence picking errors.

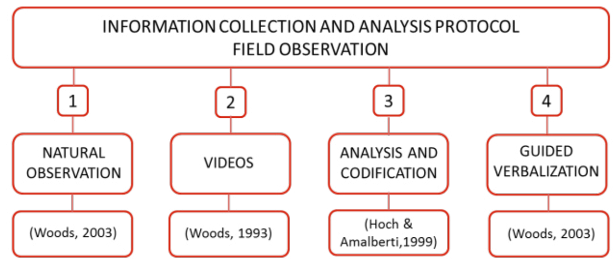

Fig. 2. Methodology

The protocol shown in Fig. 2 was implemented at *Comercial Nutresa*, a distribution center that makes use of a horizontal carousel that travels around nine picking zones. Six of them store high-rotation products distributed in several product families, each of which covers seven- to ten-meter-long shelf segments. The other three picking zones contain low-rotation product families, each occupying about ten- to sixteen-meter-long segments. Each picking zone type is served by a logistic operator. There is a warehouse management system that uses radiofrequency to send the picking orders (i.e., information on products to be picked, amounts, codes, descriptions and availability) to the operators. The study was carried out on a sample of 60 containers filled with approximately 622 picked products. 8 operators dispatched the corresponding orders during 2 days. The error ratio observed in this sample was 3%, which coincides with the error ratio of the whole picking operation at the time.

3. RESULTS

The resulting cognitive model allows for the visualization of the variables of the picking operation. It is described the terms of the tasks involved in picking as well as the information, activities and cognitive elements observed and confirmed with the operators. The first task is reading (Fig. 3), which is highly focused on the identification, on the part of the operator, of the features of the products required in the order, namely, shape, size, color and position. In this case, the cognitive activity is information identification (Rasmussen, 1982) or detection (Hoc & Amalberti, 1999). The operator establishes their mental representation (Ochanine, 1981), keeping in the operative memory the information about the requested product—the name, amount and weight—and recovering from the long-term memory the information related to product position and features. The second task is searching, wherein the operator walks to where the product is placed on the shelf. In this task, the cognitive activity consists in verifying that the requested product corresponds to the one identified on the shelf. The cognitive elements involved are attention, spatial orientation and the decision to choose a product. The third task is to actually pick the product, for which the operator uses the information stored in their operative memory (quantity) and in their long-term memory (product features and weight). This task consists of taking the requested product from the shelf, based on its amount, weight and size. According to the observation, it is at this point where errors are produced.

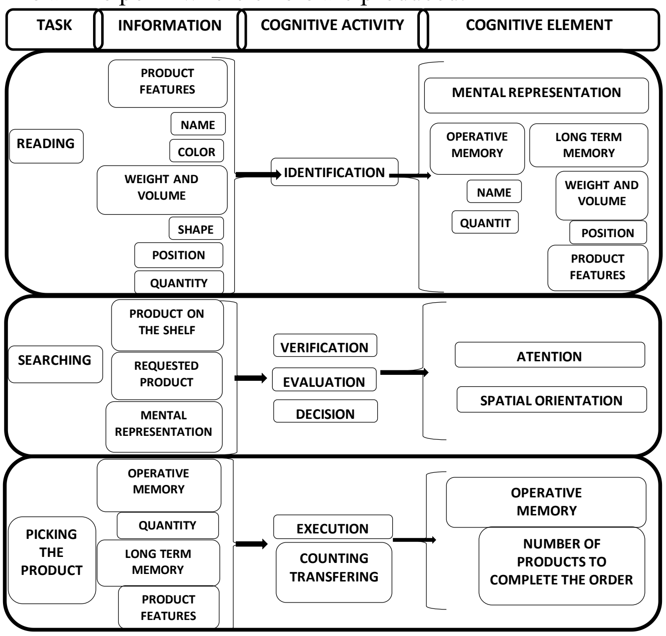

Fig. 3. Simple cognitive model

This simple cognitive model resulted from the recording, analysis and codification of the videos of the picking operation. A guided verbalization was contrasted with the analysis of 18 videos in which the errors were detected. Based on the comparison between the ordered and picked amounts, Fig. 4 illustrates the error frequency. Sixty-one percent of the errors were related to unsent products, while 39% were associated with products sent in amounts that exceeded those specified by the corresponding orders.

Fig 4. Picking errors

The guided verbalization was conducted through semi-structured interviews in which the analyst initially confirmed the task described in the model with the operator. Then, they watched the videos while the analyst asked in depth about the use of information in each task. This phase allowed for identifying the causes of errors with the collaboration of the operators (Table 1) according to the Reason (1990) error classification system and Rasmussen (1982) error taxonomy. Fifty-five percent of the causes were found to be directly related to memory.

Table. 1. Error causes

Cognitive Elements	Error sources									
	Confusion	Superficial count	Interruption	Forgetfulness	Forgetting while walking to the place	Pending	Wrong replenishment	The container goes by	The operator goes by the product	Similar locations
Attention						1		1		
Attention, Wrong instruction to the system									1	
Attention, lack of verification							1			
Attention, lack of verification			1				1			
Attention, spatial orientation										1
Counting numerous products		1								
Lack of verification							1			
Information, interpretation, attention				1						
Information, memory									1	
Memory while walking					1					
Memory while walking; counting					1					
Remembering two products while walking	1				2					
Memory, lack of verification				2						

Interestingly, product search strategy differences were observed between novice and expert operators, since the latter resorted to their experience and knowledge of the picking area, while novice operators used location coordinates. Hence, expert operators only needed the name of the product, since the rest of the information is stored in their long-term memory. This is evident from the answers of the operators when asked about the order in which they read and used the information during the picking operation. In effect, 60% of the operators (actually the most experienced ones) declared using the product's description as the informational key to start the process, while 40% (the novices) confirmed using the product's location for the same purpose.

The detailed description of the use of information by the operators, which is provided by the simple cognitive model (Fig. 5), allows the observation that in the reading task, both novices and experts use the same data: the product description, location and code. However, they resort to different memory types, since the novice needs to read the radio frequency, while the expert already keeps these features stored in their long-term memory.

Finally, in regard to the task of actually picking the product, there are no differences between the novices and experts, since they are already in front of the shelf to take the product. For such purposes, they only use their operative memory to remember the amount and weight of the product in question. It was precisely at this point where most errors were committed, since they were related to selecting wrong amounts (more or less than requested) (Fig. 4).

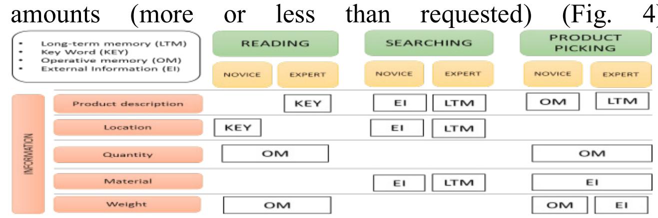

Fig. 5. Information used in picking tasks

Although this simple cognitive model reveals some perceptual and mental aspects of the picking operators' performance, as well as differences between novices and experts, field observations also revealed relationships between them and their logistic context. The variables that account for this relation are the picking zone type (high rotation, low diversity vs. low rotation, high diversity) and the combination of products to be picked, which is featured by amount, weight and size.

Picking zone types, which is related to the product search task, is featured by different product storage modes according to the demand behavior. The high-rotation zone is an approximately 10-m-long section where there are large amounts of a few products. This implies both that the operator does not have to walk long distances to search and pick a product and that there are few references to search through. In turn, the low-rotation zone, which is approximately 10 to 16 m long, stores low amounts of many different products.

Finally, the "combination of products to be picked" variable influences the actual product-picking task. This is certainly a determining factor, since it is at this particular moment when the operator selects a product and decides on its amount, thus actually making a right or wrong choice. This variable is affected by three factors, namely, the product amount, weight and volume. The hypothesis underlying this concept is that the larger the amount of a product, the higher its weight, volume and actual picking difficulty, which, in turn, increases the probability to commit a mistake.

As described below, a complex cognitive model of the picking operation results from the inclusion of the additional relationships introduced above (Fig. 6).

4. CONCLUSIONS AND FURTHER RESEARCH

The complex cognitive model of the picking operation highlights the way mental and perceptual aspects can be affected by the conditions imposed by the logistic context of picking. Fig. 6 shows how the "experience level," the "picking zone type" and the "combination of products to be picked," which is better called the order difficulty level, are likely to influence the perceptual and mental aspects such as the "information employed" or the "memorization mode" (i.e., whether the storage of information is in the operative or long-term memory), which finally affect the attention at the moment of the product selection and counting.

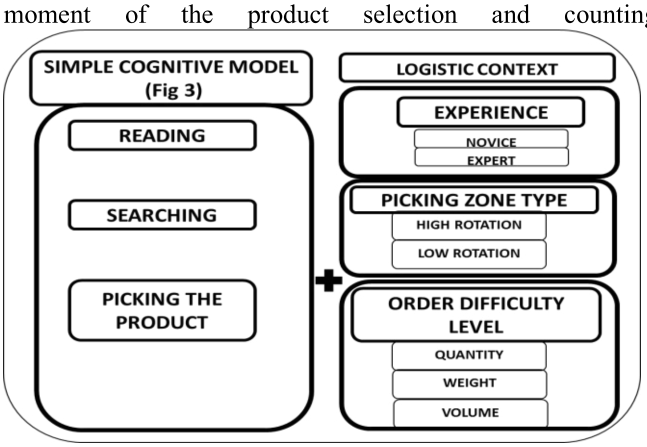

Fig. 6. Complex cognitive model based on the integration of some cognitive aspects and their logistic context.

There are some limitations in this methodology, which are related to the lack of control under the natural observation environment, since it could be possible to have some external factors associated with the operation, such as interruptions, lack of products to be picked and interactions between team members near the work station. Therefore, it is important to highlight that these limitations could decrease the accuracy of the error analysis, which needs a more controlled environment. So, further research should be conducted under controlled scenarios. However, the analysis developed in this study achieved the goal of finding the cognitive model of a picking operation based on natural observations.

The above model constitutes a preliminary qualitative approach, which should be validated through further research in controlled scenarios (Woods, 2003), thus allowing the experimental study of the factors involved, namely, experience, picking zone and difficulty level. This research could be focused on quantitative analysis as an experimental design and on qualitative analysis in order to compare the results from a natural observation to a simulated scenario where it would be possible to validate the present model and to develop a deeper representation that combines the cognitive task analysis and human error analysis in order to determine their influence on picking error.

From the current analysis, it is clear that the picking operation constitutes an interaction between human factors and their logistic context, *e.g.,* one imposed by a semi-mechanized operation.

Understanding the cognitive and logistics parameters that are likely to influence human error opens new research avenues related to the design of training or information systems, among others. These systems should include said parameters as inputs in order to improve operator performance and therefore the picking operation.

Furthermore, the current model provides elements for quantitative modeling, which could include this type of factor in order to optimize the picking operation of a supply chain.

Finally, this model constitutes a step forward in the study of the human factors of picking within the framework introduced by Grosse et al. (2014), where they are highly important for the quality and efficiency of the operation.

References

Arzu Akyuz, G., & Erman Erkan, T. (2010). Supply chain performance measurement: A literature review. *International Journal of Production Research, 48*(17), 5137-5155.

Bishu, R., Donohue, B., & Murphy, P. (1991). Cognitive ergonomics of a mail order filling company: Part 1—Influence of colour, position and highlighting on recognition time. *Applied Ergonomics, 22*(6), 367-372.

Bishu, R. R., Donohue, B., & Murphy, P. (1992). Cognitive ergonomics of a mail order filling company: Part 2 - influence of shelf coding and address information on acquisition time. *Applied Ergonomics, 23*(2), 115-120.

Brynzér, H. (1,2), & Johansson, M. I. (. 1.). (1995). Design and performance of kitting and order picking systems. *International Journal of Production Economics, 41*(1-3), 115-125. doi:10.1016/0925-5273(95)00083-6

Burinskiene, A. (2010). Order picking process at warehouses. *International Journal of Logistics Systems and Management, 6*(2), 162-178. doi:10.1504/IJLSM.2010.030958

Caro, M., Segura, T., & Quintana, L. (2014). Human error before and after the implementation of mechanized sorting system in a distribution center. Bali. 105.

De Koster, R., Le-Duc, T., & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research, 182*(2), 481-501.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*(4), 501.

Goomas, D. T., & Yeow, P. H. (2010). Ergonomics improvement in a harsh environment using an audio feedback system. *International Journal of Industrial Ergonomics, 40*(6), 767-774.

Grosse, E. H., Glock, C. H., Jaber, M. Y., & Neumann W Pattrick. (2014). Incorporating human factors in order picking planning models: Framework and research opportunities. *International Journal of Production Research,* doi:10.1080/00207543.2014.919424

Grosse, E. H., & Glock, C. H. (2013). An experimental investigation of learning effects in order picking systems. *Journal of Manufacturing Technology Management, 24*(6), 850-872.

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research, 203*(3), 539-549.

Gudehus, T., & Kotzab, H. (2009). *Comprehensive logistics* Springer.

Hoc, J., & Amalberti, R. (1999). Analyse des activités cognitives en situation dynamique: D'un cadre théorique à une méthode. *Le Travail Humain,* , 97-129.

Jaber, M., & Bonney, M. (2011). The lot sizing problem and the learning curve: A review. *Learning Curves, Theory, Models and Applications.CRC Press, Taylor and Francis Group, Boca Raton,* , 265-291.

Julesz, B. (1975). Experiments in the visual perception of texture. *Scientific American, 232*, 34-43.

Kanji, G. K., & Wong, A. (1999). Business excellence model for supply chain management. *Total Quality Management, 10*(8), 1147-1168.

Karwowski, W. (2006). The discipline of ergonomics and human factors. *Handbook of Human Factors and Ergonomics, 3*

Khan, M., Jaber, M., & Guiffrida, A. (2012). The effect of human factors on the performance of a two level supply chain. *International Journal of Production Research, 50*(2), 517-533.

Kuhlang, P., Edtmayr, T., & Sihn, W. (2011). Methodical approach to increase productivity and reduce lead time in assembly and production-logistic processes. *CIRP Journal of Manufacturing Science and Technology, 4*(1), 24-32.

Lin, C., & Lu, I. (1999). The procedure of determining the order picking strategies in distribution center. *International Journal of Production Economics, 60*, 301-307.

Ochanine, D. (1981). L'image opérative. *D.OCHANINE (Éd.)—Recuei.Université De Paris I, Séminaire D'Ergonomie,*

Pan, J. C., & Wu, M. (2009). A study of storage assignment problem for an order picking line in a pick-and-pass warehousing system. *Computers & Industrial Engineering, 57*(1), 261-268.

Powell, G. N., & Johnson, G. A. (1980). An expectancy-equity model of productive system performance. *Journal of Operations Management, 1*(1), 47-56.

Raouf, A., Jain, J., & Sathe, P. (1983). A cost-minimization model for multicharacteristic component inspection. *AIIE Transactions, 15*(3), 187-194.

Rasmussen, J. (1982). Human errors. A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents, 4*(2), 311-333.

Reason, J. (1990). *Human error* Cambridge university press.

Resnick, M. L. (2008). Human factors in complex systems: Global value chains. *IIE Annual Conference. Proceedings,* , 235-240.

Sanders, M. S., & McCormick, E. J. (1987). *Human factors in engineering and design* . McGRAW-HILL book company.

Swan, B. R. (2007). The effects of business process management cognitive resources and individual cognitive differences on outcomes of user comprehension.

Tompkins, J. A., White, J. A., Bozer, Y. A., & Tanchoco, J. M. A. (2010). *Facilities planning* John Wiley & Sons.

Weaver, K. A., Baumann, H., Starner, T., Iben, H., & Lawo, M. (2010). An empirical task analysis of warehouse order picking using head-mounted displays. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 1695-1704.

Wong, W. P., & Wong, K. Y. (2007). Supply chain performance measurement system using DEA modeling. *Industrial Management & Data Systems, 107*(3), 361-381.

Woods, D. D. (1993). Process tracing methods for the study of cognition outside of the experimental psychology laboratory. *Decision Making in Action: Models and Methods,* , 228-251.

Woods, D. D. (2003). Discovering how distributed cognitive systems work. *Handbook of Cognitive Task Design,* , 37-53.

Zink, K. J., & Seibert, S. (2009). Performance measurement from a macroergonomics perspective. *Industrial engineering and ergonomics* (pp. 91-103) Springer.