Influencing Factors for Implementing Automation in Manufacturing Businesses – A Literature Review

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Abstract. The latest developments in Robotics and Autonomous Systems (RAS) are expected to lead to a transformation of future production systems' capabilities and productivity. While increased human-robot collaboration as well as higher degrees of autonomous systems within a manufacturing context will be essential to achieve the next breakthrough in both agility as well as productivity, they will pose significant new challenges for how production systems are planned and engineered to maximise the potential and minimise the risks of this new technology for manufacturing businesses. Therefore, a main focus of this review was on determining the critical success factors for the implementation of RAS and on gaining a deeper understanding of the current research focus. The research results lead to a broader discussion of the implications arising from future automation and human-robot collaboration which highlights the current limitation of decision making criteria considered in the current literature. The results of the review have been quantitatively verified with the use of the text mining tool WordSmith Tool (v7.0).

Keywords. automation, manufacturing, influencing factors, human risks, economic risks, human-robot collaboration, RAS, MCDM.

1. Introduction

Since the financial crisis in 2007/08, it is noticeable that there has been an increasing awareness of the need for a developed economy to have a higher share of manufacturing [1]. High-value industries need to increase their competitiveness through increased productivity. Many repetitive processes have already been automated leaving only the more complex and difficult tasks. Hence, the cost of traditional fixed automation is now dramatically increasing leading to a high economical risk for those companies. Advances in human-robot collaboration and autonomous systems promise to overcome this current technology bottleneck but they also introduce new technical and social complexities. These need to be well addressed to maximise the benefit and reduce the risks associated with the introduction of these advanced manufacturing technologies to a minimum [1, 2].

From a production point of view, the aversion of workers to perform monotonous, repetitive tasks and considerations about safety; health aspects of workers, dramatic

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growth in labour rates and fringe benefits; the increased tool engineer ability to design sophisticated machinery; these have led to a great accretion of automated technology during the last few years [3]. A study by Granlund [4] shows many benefits of implementing automation in the manufacturing process, for instance, rise in labour productivity, reduction of labour cost, mitigation of the effects of labour shortages or reduced routine manual and clerical tasks as well as the improvement of workers' safety. Therefore, automation has become a great field of interest in research.

Especially, the contribution of robots to the productivity and quality improvement has been appreciatively recognized, even though the growth of the robot industry consequently leads to additional problems in many different areas. The implementation of automation and the selection of suitable robots have aggravated to a complex problem, which demands additional attention from decision-makers taking different configuration and increasing options into account [5]. Particularly, the consideration of objective and subjective criteria at the same time complicates a reasonable and repeatable methodology of decision making [6].

At the same time the technological development of RAS and towards human-robot collaboration opens up new dimensions, which have to be taken into consideration. Therefore, this literature review aims to gain an understanding of the influencing factors and areas as well as compares the results to the development of RAS and human-robot-collaboration-systems in order to justify if the automation implementation issue is being addressed in an appropriate way [7].

The second section of this paper will present the methodological approach before the results are presented in section 3 leading to an overall discussion and conclusion from the authors' perspective.

2. Methodology

2.1. Literature Sample

In order to identify the key influencing factors, the first action carried out was to collect a suitable literature corpus of papers for the last 30 years. The sample covers 150 papers and has been compiled from two different databases using the search criteria as shown in Table 1 and a manual review of abstracts. The intention of the chosen sample was to include a representative cross section of all the relevant aspects of the automation implementation process. Hence, the selected corpus includes strategic papers, operational process papers as well as papers dealing with the selection of technologies. The databases were selected with the aim to gather representative literature within the mentioned research area. Although the sample is not exhaustive, the authors contend that it is a representative corpus to analyse due to the cross database search functions within the sample.

Table 1: Literature search terms and databases

Search words	Database	Cross database search
Automation, Manufacturing, Technology Selection.	Web of Science	Yes
MCDM, Manufacturing, Technology Selection.	Web of Science	Yes
Selection of automation projects.	Web of Science	Yes
Operations Process Management, automation, manufacturing.	Emerald Insight	No

2.2. Research Approach

The existing literature identifies a catalogue of objective and subjective criteria which represents a large body of expert knowledge (see for example [8]). This paper is reviewing this body of knowledge to identify most prominent factors used to select and investigate the success of automation technology.

A manual approach has been used to identify the most frequently used success factors and evaluation criteria in the collected text corpus. The results of the manual annotation have been compared to those of a text mining tool (WordSmith Tool v7.0). The text mining program was used to extract success factors within the literature to ensure that the frequencies identified manually are comparable. This approach is not relying on the opinions of individual experts but is looking at the underlying consensus and trends reported in the literature. The overall approach is shown in Figure 1.

For the text mining approach, the selected papers were converted from PDF into text files. The first step is to create a wordlist, which contains all the mentioned words within the texts. To avoid collecting any meaningless words, a stopwords list (e.g. and, the) was used to force the program to ignore them and a lemma list was used to find a collection of root words (e.g. costing, cost). The program presents a list of words and their frequencies as well as the number of documents they are mentioned in. This list has been separated into two parts: (i) to identify the research areas and (ii) to show the different success factors. This provided the basis for a cluster analysis which defines relations based on co-occurrences of root words.

However, it is worth noting that this methodology only extracts new relations and orders. It does not find new concepts. The adopted approach gives an indication of the most frequently mentioned factors, which is expected to be indicative of their importance. The following section presents the main results of the analysis.

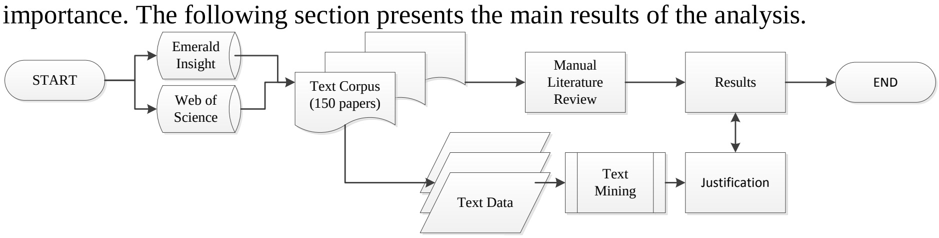

Figure 1: Applied research methodology.

3. Results

3.1. Influencing factors for the implementation of automation

Figure 2 shows the 30 most influential (frequent) factors extracted by the manual review process. The results appear very predictable with many different categories of *monetary quantities* like investment (costs), operating costs, total costs of ownership (TCO) as well as *productivity* and *economic performance* in the first positions. There is a collection of related *technical performance* indicators including, for instance, flexibility, capacity, product quality, repeatability and reliability, productivity, speed and throughput rate. Furthermore, the results also include soft factors[2] such as the

[2] Not directly measurable factor.

vendor support, the technological leadership/ level, ease of implementation and use, IT-integration and implementation or safety and ergonomics.

The soft factors are generally considered as part of a multi-criteria decision-making (MCDM) problem that combines measurable and unmeasurable variables. Roughly, a third of all the papers apply a MCDM methodology e.g. for selection of an industrial robot selection [8]. In fact, more than a half of the papers focus on the selection of industrial robots [9]. It is also noticeable that over 95% of the documents focus on either the reduction of financial or economic risks, or both.

The results from the *WordSmith Tool* broadly confirm the findings of the manual review showing that cost is the most important factor appearing in almost 100 percent of the collected corpus. At the same time, the cluster analysis highlights the importance of ‘robot selection’ (rank 1: 431 hits in total) and a ‘flexible manufacturing system’ (rank 2: 326 hits in total) within the overall frequency of the documents. Based on those results, it can be seen that flexibility as well as robot selection (technical performance) are considered as very important factors for the implementation.

For brevity, the authors relinquished the detailed illustration of the text mining results, which have been extracted from the wordlists and clusters. Nevertheless, a more detailed look on the technology shift in combination with the extracted factors leads to a further understanding of the risks considered.

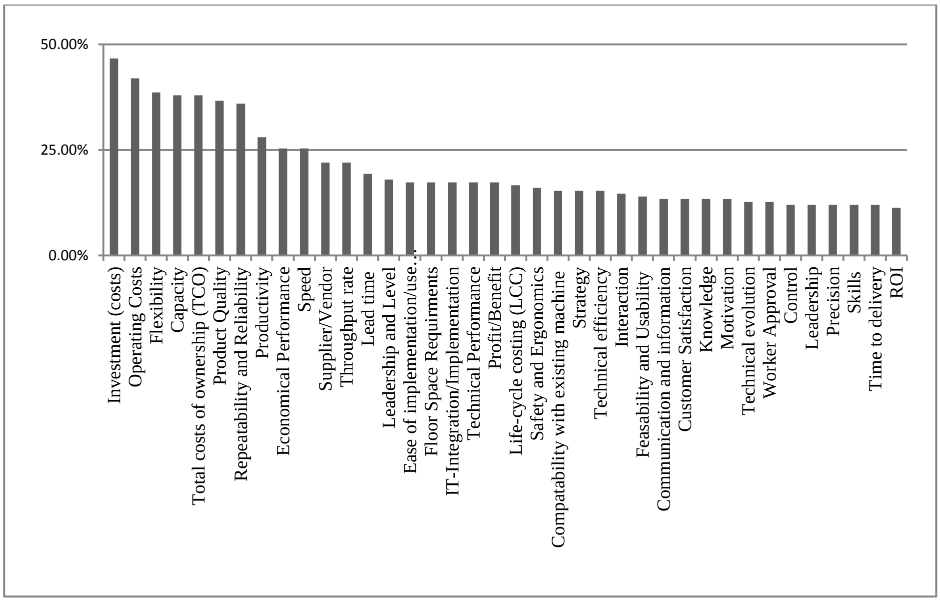

Figure 2: Proportion of 30 most critical success factor frequencies for the implementation of automation within the text corpus.

3.2. Economic risks vs. human risks

One of the key findings is that there has been a significant interest in economic risks and the technical performance of automation implementation so far (e.g.[10]–[12]). However, *as human-robot collaboration* and *autonomous systems* are becoming a more influential area for technology innovation providing the *benefits of flexible* *manufacturing systems*, which seem to be highly estimated [4, 20], it is expected that *human factors* and *systems-of-systems approaches* will become more important. While the results suggest that aspects of human risks like ‘safety and ergonomics’, ‘motivation’ or ‘worker approval’ have been considered in the past, they appeared much less frequently than the economic risks. This is an indication of more limited research in this area. Therefore, according to the results, there is a reasonable doubt whether human risk has been sufficiently explored in the context of new emerging automation paradigms (Figure 3). The statistical results created by the text mining tool show that the word ‘human’ appears on the 50th position in the overall frequency of words. It has, however, been noted that there is an increasing awareness of human-robot collaboration issues such as symbiotic assembly system paradigm and path-tracking, and collision-avoiding systems [13, 14].

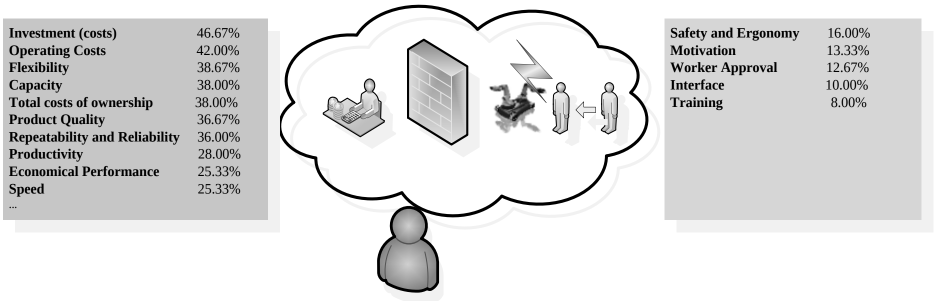

Figure 3: Differences in consideration of economic risks (left side) and human risks (right side) defined by the proportion of texts a factor is mentioned in.

4. Discussions and Conclusion

The overall impressions gained during the manual review process are that the current discussion of automation has reached an impasse in several different ways. First of all, in many cases automation is treated synonymous to the use of industrial robots only. A possible reasonable explanation could be the various appearances of advanced manufacturing technologies forcing the researchers to narrow down to robots disregarding the wider systems perspective. With advances in human-robot systems and more advanced autonomy, the very robot centric research and discussion will have to shift to taking further factors, such as psychological implications of collaborative robots or the interaction in multi-actor systems, into account. This leads to the conclusion that soft factors, like health and safety as well as worker approval and how they relate to the economic and technical performances, will necessarily be of greater interest for the automation process. Therefore, the focus of future research should be aligned to future needs of the manufacturing area.

Moreover, many papers are focusing on the methodology of multi-criteria decision-making. A large part of the literature within this area seems to be focused more on mathematical or methodological point of view rather than the technological, economic and sociological realities of the problem, which they use to test the efficiency of their methods. Frequently, the implementation of automation and robot selection are used as an example for MCDM methodology but not to solve the actual selection and implementation problems.

Economic risks are clearly the main concern. In particular, Total Cost of Ownership and Life-Cycle Costing have been cited frequently (Figure 2). However, a more detailed investigation suggests an insufficient consideration of more comprehensive costing models in this research area. The complexity of automation implementation seems to be a limiting factor for the simultaneous use of various models. For instance, the combination of life-cycle costing and multi-criteria decision making models established by Boubekri [15] has not been further explored.

The review has generated various interesting observations informing future research directions. One limitation of the approach adopted so far is that factors not reported in the literature will not be identified. This will require primary data collection from surveys or case studies.

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References

[1] T. Bauernhansl, M. ten Hompel, and M. Henke, *Industrie 4.0 in Produktion, Automatisierung und Logistik*. 2014.

[2] James Manyika, Jeff Sinclair, Richard Dobbs, G. Strube, L. Rassey, J. Mischke, J. Remes, C. Roxburgh, K. George, D. O'Halloran, and S. Ramaswamy, "Manufacturing the future: The next era of global growth and innovation," *McKinsey Glob. Inst.*, no. November, p. 184, 2012.

[3] R. Crowson, *Assembly processes: finishing, packaging, and automation*. CRC Press, 2006.

[4] A. Granlund, *Competitive Internal Logistic Systems Through Automation*, no. 137. 2011.

[5] G. Liang, "A fuzzy multi-criteria decision-making approach for robot selection," *Robot. Comput. Integr. Manuf.*, vol. 10, no. 4, pp. 267–274, 1993.

[6] S. Vinodh, T. S. Sai Balagi, and A. Patil, "A hybrid MCDM approach for agile concept selection using fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS," *Int. J. Adv. Manuf. Technol.*, vol. 26, no. 3, pp. 369–388, 2015.

[7] J. R. Meredith, "Implementing the automated factory," *J. Manuf. Syst.*, vol. 6, no. 1, pp. 1–13, 1987.

[8] R. Parameshwaran, S. Praveen Kumar, and K. Saravanakumar, "An integrated fuzzy MCDM based approach for robot selection considering objective and subjective criteria," *Appl. Soft Comput. J.*, vol. 26, pp. 31–41, 2015.

[9] D. K. Sen, S. Datta, S. K. Patel, and S. S. Mahapatra, "Multi-criteria decision making towards selection of industrial robot Exploration of PROMETHEE II method," *J. Small Bus. Enterp. Dev.*, vol. 12, no. 4, pp. 564–578, 2005.

[10] D. J. Adler, J. A. Herkamp, J. R. Wiesler, and S. B. Williams, "Life cycle cost and benefits of process automation in bulk pharmaceuticals," *ISA Trans.*, vol. 34, no. 2, pp. 133–139, 1995.

[11] Y. M. G. Y. M. Goh, L. B. Newnes, A. R. Mileham, C. a. McMahon, and M. E. Saravi, "Uncertainty in Through-Life Costing- Review and Perspectives," *IEEE Trans. Eng. Manag.*, vol. 57, no. 4, pp. 689–701, 2010.

[12] H. S. Shih, "Incremental analysis for MCDM with an application to group TOPSIS," *Eur. J. Oper. Res.*, vol. 186, no. 2, pp. 720–734, 2008.

[13] P. Ferreira, S. Doltsinis, and N. Lohse, "Symbiotic assembly systems - A new paradigm," *Procedia CIRP*, vol. 17, pp. 26–31, 2014.

[14] J. Pomares, F. A. Candelas, F. Torres, J. A. Corrales, and G. J. Garc??a, "Safe human-robot cooperation based on an adaptive time-independent image path tracker," *Int. J. Innov. Comput. Inf. Control*, vol. 6, no. 9, pp. 3819–3842, 2010.

[15] N. Boubekri, M. Sahoui, and C. Lakrib, "Development of an expert system for industrial robot selection," *Comput. Ind. Eng.*, vol. 20, no. 1, pp. 119–127, 1991.