The statistical sampling about levels of utilization of multi-criteria methods to solve problems in POM

Isabela Cristina Pessoa
Flavio Trojan
Gilson Adamczuk Oliveira
Dalmarino Setti
Federal University of Technology, Parana, Brazil
Corresponding author: trojan@utfpr.edu.br

Abstract
This paper shows statistical sampling results on levels of utilization of multi-criteria methods for problems in productive environments, operations and management. 820 articles were filtered from 7,725 publications considering publication quality standard in Brazil and Impact Factor. Descriptive statistics was used to represent data and analysis from 2004 to 2014.

Keywords: Decision making, Multi-criteria methods, Production and operations management.

Introduction

Nowadays the decision analysis in all productive processes involves some degree of detailing, which subdivides the problem analyzed into different points of view and considers different criteria in this analysis. The multi-criteria analysis has been an important tool that supports decisions while the production is increased day by day. Whenever a wrong decision is made, in other words, if the criteria are not considered properly, the probability to lose production, clients and profitability is high. Decisions are present all the time in production systems, operation systems and mainly in the management efficiency. In order to support decisions necessary to manage systems, an expressive number of multi-criteria methods and models have been developed, each one with specific characteristics and applicable to the various areas of production engineering.

Due to the MCDM importance (Multi-criteria Decision Making) in the decision process, it becomes imperative to know "where", "how" and "the amount by which" the multi-criteria methods have been applied. Depending on the characteristic of the problem, there is a great amount of multi-criteria methods available for solution. The best application of a method is going to lead to a good solution just whenever the appropriate criteria were considered for each scenario. So, there is a wide variety of applications available in the literature.

This paper develops research on the amount of multi-criteria methods applied and referenced in production engineering, operations and management. First of all indexed databases of international journals were consulted and the most used methods with multi-criteria decision making approach identified. In the sequence, stratification was constructed, considering the most qualified publications based on quality standard publications in Brazil, Impact Factor (IF) and

Journal Citation Report (JCR). The data collected were organized through the descriptive statistics and by high impact factor JCR, in order to detect the area in which multi-criteria methods are efficient or most usually applied.

The results aim to provide an overview of the applications which involve the construction and analysis of decisions with multi-criteria methods, sorted by their common characteristics. The main objective of this work is to contribute to know more about the applications and development of the multi-criteria methods in the production and operations management, showing a perspective of "how" and "where" the methods are being used, as well as the main problems that are being solved through these methods.

Review

The earliest known reference to Multiple Criteria Decision Making can be traced back to Benjamin Franklin (1706 - 1790), who allegedly had a simple paper system for deciding important issues. *"Take a sheet of paper. On one side, write the arguments in favor of a decision; on the other side, write the arguments against. Strike out arguments on each side of the paper that are relatively of equal importance. When all the arguments on one side are struck out, the side which has the remaining arguments is the side of the argument that should be supported"*. Supposedly Franklin used this in making important decisions (MCDM, 2012). The multi-criteria analysis historical developments are presented in Table 1.

Table 1 – Historical developments in multi-criteria analysis

Authors	Period	Development
Kuhn and Tucker	1951	The authors formulated optimality conditions for nonlinear programming. They also considered problems with multiple objectives.
Charnes, Cooper and Ferguson	1955	An article was published that contained the essence of goal programming, even though the name ‘goal programming’ was first used in a book published by the authors in 1961.
Ron Howard and G.E. Kimball	1959	It is believed that they used the term "decision analysis" for the first time during the mid-1960s.
Bernard Roy	mid-1960's	He developed the ELECTRE´s methods. It is a family of Multi-Criteria Decision Analysis methods.
Bruno Contini and Stan Zionts	1968	A multiple-criteria negotiating model was developed.
Howard Raiffa	1968	He had been involved in decision analysis early on, and published an important work.
Thomas Saaty	1970s	He introduced the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) more recently. Saaty is one of the most visibly successful people in MCDM, who has been cited in the Fortune magazine.
Milan Zeleny and J. L. Cochrane	1972	They organized an international conference on MCDM in Columbia, South Carolina.
Zionts and Jyrki Wallenius	1973	They developed the Zionts-Wallenius interactive method for solving multiple-objective linear programming problems.
Bernard Roy	1975	He founded the EURO Working Group "Multiple Criteria Decision Aiding".

Authors	Period	Development
Ralph Keeney and Howard Raiffa	1976	They published an important book that was instrumental in establishing the theory of multi-attribute value theory (including utility theory) as a discipline. It became a standard reference and text for many generations of study of decision analysis.

Source: MCDM (2012)

Deriving from these historical developments the multi-criteria methods have evolved and have been used in a great number of applications related to production and operations management issues. Currently, there is infinity of multi-criteria methods that were developed by their authors according to the problem in question. Each method presents a specific problematic in decision making (Zopounidis and Doumpos, 2002).

Roy (1996) established four problematics that could be explored in multi-criteria analysis: (i) Problematic of Selection (Pα): it selects the best alternative(s); (ii) Problematic of Classification (Pβ): it allocates alternatives in homogeneous categories; (iii) Problematic of Ordination (Pγ): it has the objective of ordinating alternatives, considering "from the best to the worst" ordination and (iv) Problematic of Description (Pδ): it describes and relates information about the performance of established criteria in order to identify the characteristics of each action.

The choice of a method will depend on the scenario and characteristics of the research problem (Gomes and Gomes, 2014). Nowadays, there are not many studies on the statistical uses of multi-criteria methods in every production segments.

Malczewski (2006) developed a survey about GIS (Geographic Information System) and MCDA. In Malczewski´s paper the GIS-MCDA approaches were reviewed using literature review and classification of articles from 1990 to 2004. An electronic search indicated that over 300 articles appeared in referred journals. The paper provided taxonomy of those articles and identified trends and developments in GIS-MCDA. 319 articles were classified according to their application domains such as: Environment and Ecology; Transportation; Urban and Regional planning; Waste management; Hydrology and Water resource; Agriculture; Forestry; Natural hazard; Recreation and Tourism; Housing and Real estate; Geology and Geomorphology; Manufacturing; Cartography and Miscellaneous. All of these issues related with GIS applications.

Also Aruldoss *et al.* (2013) carried out a survey about a sampling of 30 contributions of some multi-criteria fuzzy methods and their applications. It presented occurrences such as: TOPSIS(30.0%); FuzzyAHP (20.0%); FuzzyMCDM (16,7%); ELECTRE (16,7%); other methods (10.0%) and VIKOR (6,6%).

Methodology: data collection search procedures and analysis

In this work we are interested in generating knowledge about applications and uses of multi-criteria methods related to industrial productions and operations management. In order to clarify this research phases, an overview of the survey structure is presented in Figure 1.

- Key words definition: in this phase the key words related with the theme and their relevance in the general context of the multi-criteria approach were defined.

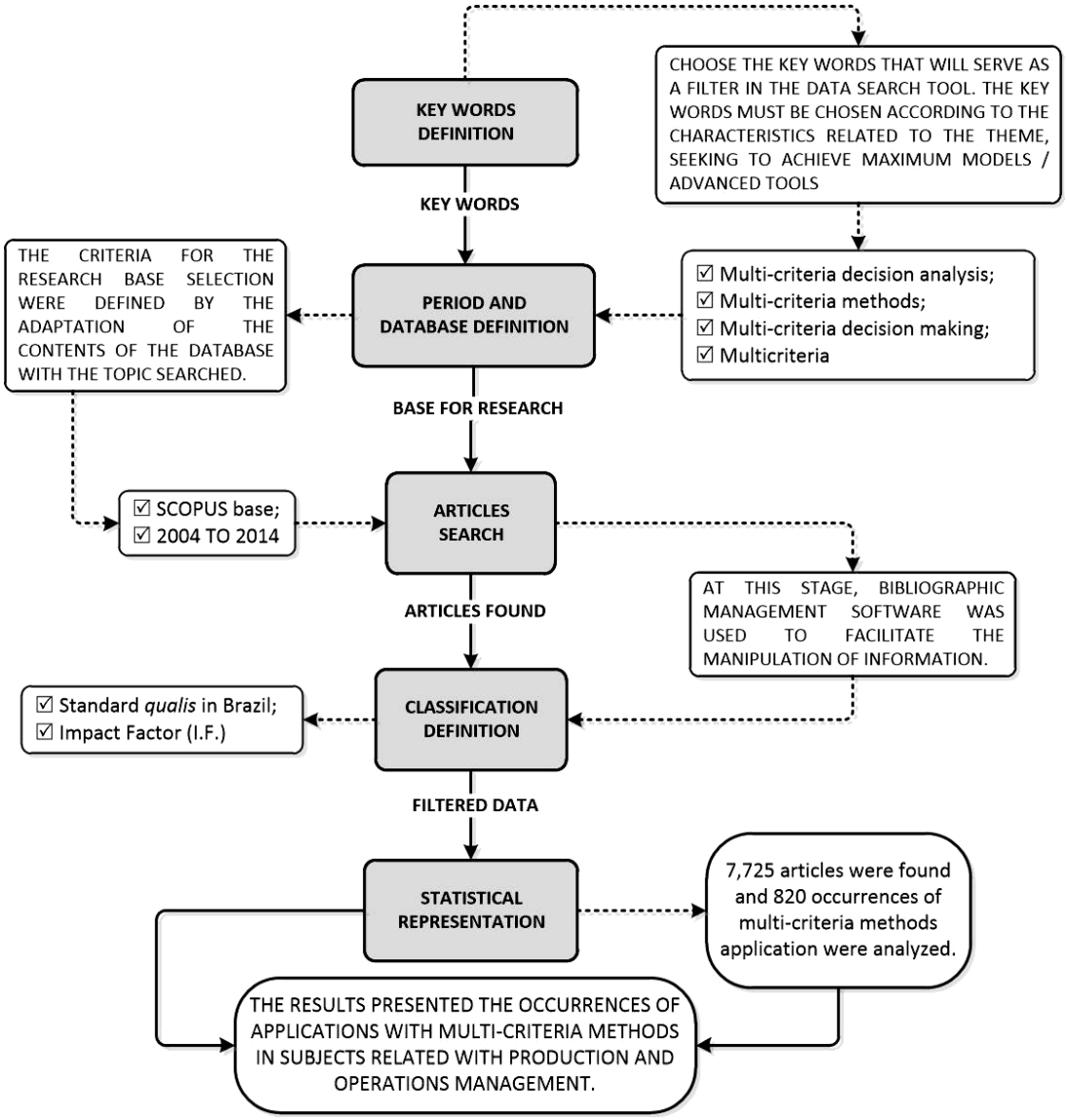

Figure 1 – Research structure

- Database and period definition: the database used was the Scopus. According to Bar-Ilan (2008), the Scopus database has been widely utilized as a data source for studies which describe the dynamics of science and technology. The period chosen was throughout the last10 years, i.e., 2004 to 2014.
- Articles search: Articles were searched by title and abstract, mainly referring to multi-criteria methods applications in production and operations management. Bibliographic manager software was used to support this operation.
- Classification: It was based on standard *qualis* in Brazil and the Impact Factor and JCR (Journal Citation Report). The articles allocated in this classification were the basis for the next investigation.
- Deep research: In order to verify the relations of the articles with the theme under study, every abstract was read and the multi-criteria methods featured in each explored paper were identified.

- Filtered works: All the works consulted were analyzed and the multi-criteria methods were identified according to the theme and its applications.
- Data analysis and statistical representation: After the investigation phase was completed, the resulting information was represented in a statistical form. It was done with time series setting, through exponential adjustment models, including the linear model by graphical analysis of previous data. After that the best model was chosen by the Akaike information criterion (Akaike, 1974).

Data presentation and results analysis

The number of articles which were published in the decade 2004-2014 was explored. The numbers of publications were analyzed to show views about the applications of the multi-criteria methods, specifically linked with production engineering and operations management. Bibliometry was used to show the scientific production quantitative aspects according to the definitions presented by the authors Tague-sutckiffe (1992); Li and Zhao (2014).

The volume of articles researched was around 13,634 articles. Repeated articles were excluded, totaling 7,725 articles. In the sequence these articles were filtered based on the quality standard publications in Brazil (*qualis*), and 3,089 articles were reached. Finally, another filter was applied in order to explore only the articles in which the multi-criteria methods were addressed. The final number of articles that were analyzed in this approach totaled 820 articles. These articles were really linked to the theme of this proposal.

Table 2 presents information about this statistical sampling, derived from the procedures developed in this work. It demonstrates that the average and the median have a decrease. On the other hand, the number of publications has significantly increased in the period 2004 to 2013.

Table 2 – Statistical data presentation

Pub. Year	Count	Average I.F.	Median	Stand. Deviat.	Coeff. of variation
2004	25	2.56	2.46	1.10	44.89%
2005	23	2.16	1.84	1.02	55.69%
2006	33	2.27	1.84	1.07	58.48%
2007	49	2.14	2.02	0.84	41.82%
2008	66	2.14	1.90	0.92	48.34%
2009	85	2.01	1.96	0.78	40.05%
2010	96	2.12	1.96	1.01	51.52%
2011	113	2.13	1.96	0.90	46.04%
2012	103	1.92	1.87	0.95	50.67%
2013	126	2.09	1.77	1.28	72.56%
2014	101	2.03	1.96	1.13	57.81%
Total	**820**	**2.14**	**1.96**		

Figure 2 graphically demonstrates a box plot of the data sequence, related to the multi-criteria methods, their occurrences in journals and the impact factor rates in which each method occurs. With this procedure, it is possible to visualize graphically some variations in the quality of the publications and the methods applications.

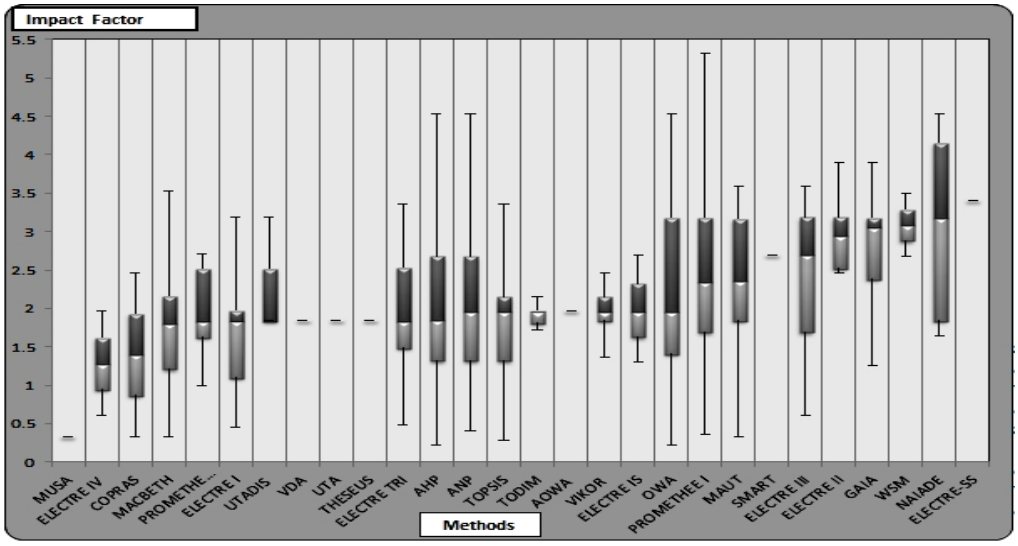

Figure 2 - Box Plot representation

Table 3 - Statistical data by Impact Factor ranges

	Methods	F.I. Average	Standard Deviation	IMPACT FACTOR BETWEEN						Count	%
				0 ⊣ 0.5	0.5 ⊣ 1.0	1.0 ⊣ 2.0	2.0 ⊣ 3.0	3.0 ⊣ 4.0	4.0 ⊣ 6.0		
1	AHP	2.04	1.02	14	27	167	55	40	19	**322**	39.3
2	TOPSIS	2.02	0.99	4	13	80	20	9	7	**133**	16.2
3	ANP	2.08	0.99	3	7	31	16	10	4	**71**	8.7
4	PROMETHEE I	2.49	1.20	2	5	20	9	19	8	**63**	7.7
5	VIKOR	2.07	0.75	1	2	22	10	4	1	**40**	4.9
6	ELECTRE I	1.76	0.86	1	4	14	3	2	1	**25**	3.0
7	OWA	2.26	1.09	1	1	12	2	6	2	**24**	2.9
8	ELECTRE III	2.38	0.95	0	1	9	4	9	0	**23**	2.8
9	MAUT	2.37	0.84	1	0	7	6	7	0	**21**	2.6
10	GAIA	2.96	0.82	0	0	3	4	9	2	**18**	2.2
11	ELECTRE TRI	2.11	1.05	2	0	9	2	2	2	**17**	2.1
12	PROMETHEE II	2.17	1.01	0	1	7	4	0	1	**13**	1.6
13	MACBETH	1.80	0.98	2	0	4	2	2	0	**10**	1.2
14	TODIM	1.84	0.32	0	0	5	2	0	0	**7**	0.9
15	ELECTRE II	2.74	0.99	0	1	0	2	2	0	**5**	0.6
16	NAIADE	3.08	1.31	0	0	2	0	1	2	**5**	0.6
17	UTA	1.81	1.01	0	0	3	0	1	0	**4**	0.5
18	ELECTRE IS	1.99	0.70	0	0	2	1	0	0	**3**	0.4
19	UTADIS	2.29	0.78	0	0	2	0	1	0	**3**	0.4
20	COPRAS	1.40	1.51	1	0	0	1	0	0	**2**	0.2
21	ELECTRE IV	1.29	0.96	0	1	1	0	0	0	**2**	0.2
22	SMART	2.70	0.00	0	0	0	2	0	0	**2**	0.2
23	WSM	3.09	0.58	0	0	0	1	1	0	**2**	0.2
24	AOWA	1.96	-	0	0	1	0	0	0	**1**	0.1
25	ELECTRE-SS	3.41	-	0	0	0	0	1	0	**1**	0.1
26	MUSA	0.33	-	1	0	0	0	0	0	**1**	0.1
27	THESEUS	1.84	-	0	0	1	0	0	0	**1**	0.1
28	VDA	1.84	-	0	0	1	0	0	0	**1**	0.1
SUM				**33**	**63**	**403**	**146**	**126**	**49**	**820**	100.0
Percentage (%)				4.0	7.7	49.1	17.8	15.4	6.0	100.0	

Table 3 presents an overview of the methods distribution into the impact factor ranges. It is possible to notice the AHP method as the most usually applied with 39.3% or 322 occurrences and in journals with 2.04 scores to impact factor on average, followed by the TOPSYS method with 16.2%; ANP with 8.7% of occurrences and PROMETHEE I with 7.7%. In this sampling, the global results show that 49.1% of the articles were published between the ranges 1.0 to 2.0 impact factor.

Other variations and dispersions can also be visualized in the Box plot of Figure 2.

Table 4 - Data distribution per application areas

Methods	Operations	Production	Management	Engineering	Environment	Energy	Others	Total
AHP	36	33	67	90	46	40	10	322
TOPSIS	5	15	3	76	8	16	10	133
ANP	2	8	8	34	5	7	7	71
PROMETHEE I	10	4	5	18	9	8	9	63
VIKOR	2	4	8	18	2	2	4	40
ELECTRE I	5	3	1	12	-	1	3	25
OWA	3	3	-	12	3	-	3	24
ELECTRE III	5	2	3	3	5	4	1	23
MAUT	7	1	6	3	2	-	2	21
GAIA	1	-	2	6	6	1	2	18
ELECTRE TRI	6	-	1	4	1	3	2	17
PROMETHEE II	2	-	1	4	-	2	4	13
MACBETH	2	2	3	1	1	-	1	10
TODIM	2	-	-	5	-	-	-	7
ELECTRE II	-	1	2	1	1	-	-	5
NAIADE	1	-	1	1	1	1	-	5
UTA	1	1	2	-	-	-	-	4
ELECTRE IS	-	-	-	2	-	1	-	3
UTADIS	3	-	-	-	-	-	-	3
COPRAS	-	-	-	1	-	1	-	2
ELECTRE IV	-	-	-	2	-	-	-	2
SMART	2	-	-	-	-	-	-	2
WSM	-	-	-	-	-	-	2	2
AOWA	-	-	-	1	-	-	-	1
ELECTRE-SS	-	-	-	-	-	1	-	1
MUSA	-	-	-	-	-	-	1	1
THESEUS	1	-	-	-	-	-	-	1
VDA	1	-	-	-	-	-	-	1
TOTAL	**97**	**77**	**113**	**294**	**90**	**88**	**61**	**820**
%	**11.8**	**9.4**	**13.8**	**35.9**	**11.0**	**10.7**	**7.4**	**100.0**

The data presentation in Table 4 has the objective to know the application areas distribution of the multi-criteria methods related to production processes. The articles were allocated in their positions according to the main characteristic found in their publications, which identified the area in which each method has been utilized. It denotes that approximately 36.0% of the methods were utilized in the Engineering area, followed by Management (13.8%); Operations (11.8%); Environment (11.0%); Energy (10.7%); Production (9.4%) and other applications (7.4%).

Figure 3 shows the data compiled and a growing trend of multiple criteria methods use over the years in publications can be observed. The time series shows best fit linear behavior. It includes the forecast for 2014, 2015 and 2016. Thus, it was observed that in 2016, according to the criteria and filters, 150 items will be potentially published in MCDM.

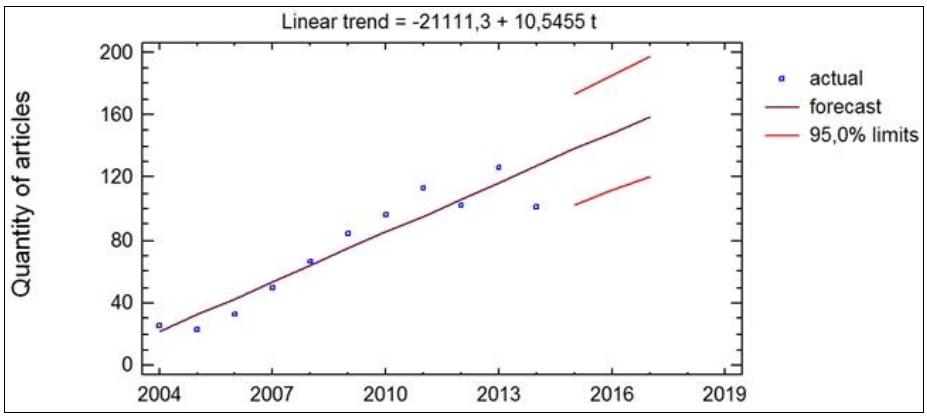

Figure 3 – 2004-2013 time series adjustment and 2014-2016 forecast

Final remarks

In the course of time, social and scientific changes motivated the need to develop new interconnections among the theory, production arrangements and empirical practice.

Thus, this work brought some contribution by showing its methodology through statistical sampling in Brazil, which demonstrated ″how″ and ″where″ multi-criteria methods have been utilized lately. This information is relevant in order to support the decision makers when there is a need to make an important decision in a specific area, for example. Here, we also presented some trends and distributions regarding multi-criteria methods applications, linked to production, engineering, operations, environment, energy and management areas.

Thus, the interest of the work presented here arose from the need to know what was published in the last 10 years (2004-2014) in journals of higher impact factor in Brazil and owned by JCR, in the production and operations management area, limiting data collection in search Multi-criteria Tools Supports Decision, enabling descriptive statistics analysis.

In the period researched, i.e, 2004 to 2014 it was possible to identify 820 works related to multi-criteria methods, production and operations management. The three most applied methods were AHP, TOPSYS and ANP. The average impact factor in the publications was 2.147. After the linear adjustment, it was possible to notice increasing trends in publications and the projection for new publications which involve multi-criteria methods solving problems in production and operations management is approximately 150 articles in 2016. This overview can be employed as an application guide for decision makers and researchers into the MCDM area. However, we know that all research needs to be improved and this work presents only a sampling to apply a methodology.

Thus, some limitations can be detected in this work, which requires improvement of certain points such as: (i) the bibliographic research was restricted to journals based on impact factor and standard in Brazil. It needs to be widely improved in order to provide a more global overview; (ii) the database considered was the Scopus only. We also believe that this research needs to be expanded.

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