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Title

Multi Criteria Decision Analysis Software in Health Care Priority Setting - A Systematic Review

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Abstract

Objective: To identify studies using Multi Criteria Decision Analysis (MCDA) software tools to support health prioritisation processes and to describe the technical capabilities of the MCDA software tools identified.

Methods: First, a systematic literature review was conducted in Medline, Embase, Web of Science, Econlit and Cochrane databases in July 2019, to identify studies that have used MCDA software for priority setting in health-related problems. Second, the MCDA software tools found in the review were downloaded (full versions, where freely available, and trial versions otherwise) and tested to extract their key technical characteristics.

Results: Nine studies were included, from which seven different software: 1000minds, M-MACBETH, Socio Technical Allocation of Resources (STAR), Strategic Multi-Attribute Ranking Tool (SMART), Visual PROMETHEE, EVIDEM and Prioritisation Framework were identified. These software tools differed in terms of the operating systems (including web interface), MCDA technique(s) available for use, visualization features and the capability to perform Value for Money (VfM) and sensitivity analyses.

Conclusions: The use of MCDA software in prioritization processes has a number of advantages such as inclusion of several types of stakeholders, ability to analyse a greater number of alternatives and criteria and perform real time sensitivity analyses. Proprietary software (i.e. software with licensing fees) seemed to have more features compared to freely available software. However, this field is still developing, with only a few studies where MCDA software was used to support health priority setting and opportunity costs not explicitly captured in many software.

Key points for Decision Makers

There are many MCDA software tools available to support priority setting in health care, which differ in terms of the operating systems (including web interface), MCDA technique(s) available for use, visualization features and the capability to perform Value for Money (VfM) and sensitivity analyses.

Proprietary software (i.e. software with licensing fees) seem to have more features compared to freely available software.

However, this field is still developing, with only a few studies where MCDA software was used to support health priority setting, and costs and considerations of opportunity costs not explicitly captured in many software.

1. Introduction

Given the scarce health care resources, increasing number of new health technologies (many of them of high cost) and the conflicting objectives of stakeholders, priority setting in healthcare is not only necessary, but also one of the most complex and sensitive tasks [1,2]. Consequently, many countries have decided to establish systematic and rational mechanisms, with explicit criteria and a structured institutional framework for health technologies prioritisation [3–9].

Multi criteria decision analysis (MCDA) has been used as a transparent, participatory framework for supporting decision making and policy setting in healthcare [8,10,11]. The benefits of MCDA approaches include supporting stakeholders through the process, aligning investments in health technologies with their preferences/needs and providing legitimacy to the decision-making process [12]. MCDA process broadly involves problem structuring (i.e. selection of participants, alternatives and criteria); MCDA modelling (i.e. weighting, scoring and aggregation); and decision-making (i.e. interpretation of results and decision-making) [13].

Reviews on the use of MCDA in healthcare decision-making [14,15] suggested that most MCDA studies have typically been pilot studies or bespoke analysis (i.e. without the use of multi-criteria software). The MCDA processes are usually performed using paper forms or templates filled out manually or using spreadsheets to collect the preferences of the participants [16,17]. Most of the MCDA studies did not use the computational tools available to address these problems. Given priority setting in healthcare is often associated with a large number of interventions along with multiple criteria and stakeholders, the use of manual MCDA approaches has several limitations including cognitive burden, implementation difficulties, and the inability to perform sensitivity and scenario analyses.

There is a range of MCDA software available that can support priority setting processes [18]. The benefits of using MCDA software include facilitating data manipulation, reducing transcription errors, allowing the immediate feedback of the results, and the capability to allow multiple simultaneous users. However, despite the availability of MCDA software, their use in the health care field is still in its infancy [19].

This study aims to review systematically studies that used MCDA software to support priority setting in healthcare and to summarise the technical characteristics of the MCDA software identified in the review. The potential beneficiaries of this review include the decision makers considering using MCDA software to support priority setting process in health care; researchers that are interested in facilitating MCDA studies to support health care priority setting; and developers of MCDA software to support health care priority setting

The rest of the article is structured as follows. Section 2 describes the methods of the systematic review and the methods to identify the software and describe the key features. Section 3 presents the results of the systematic review and the technical capabilities of the MCDA software tools identified. Section 4 presents the discussion of the findings along with considerations for the use of MCDA tools to support prioritisation in health care.

2. Methods

2.1 Systematic review of studies using MCDA software for priority setting

The aim of the review was to identify studies that have used MCDA software tools to support decision-making processes in the context of health technologies prioritisation. This section provides details about the

methods of the systematic review including the literature searches, study selection and data extraction and analysis.

2.1.1 Literature Searches

Searches were carried out in the relevant academic databases (Medline, Embase, Web of Science, Econlit and Cochrane), reference lists and grey literature in Google Scholar, in July 2019. The search terms related to "software", "prioritization processes" and "health". Appendix 1 presents the search strategies for each database. The reference lists of the included studies were also searched to identify relevant studies.

2.1.2 Study selection

The papers considered for inclusion were those that implemented or adopted MCDA software for priority setting in health-related problems. Conversely, studies were excluded if they did not use MCDA, did not involve prioritization problems or if the prioritization was not related to health, or if they used software but not directly to support the MCDA process (for example, statistical packages).

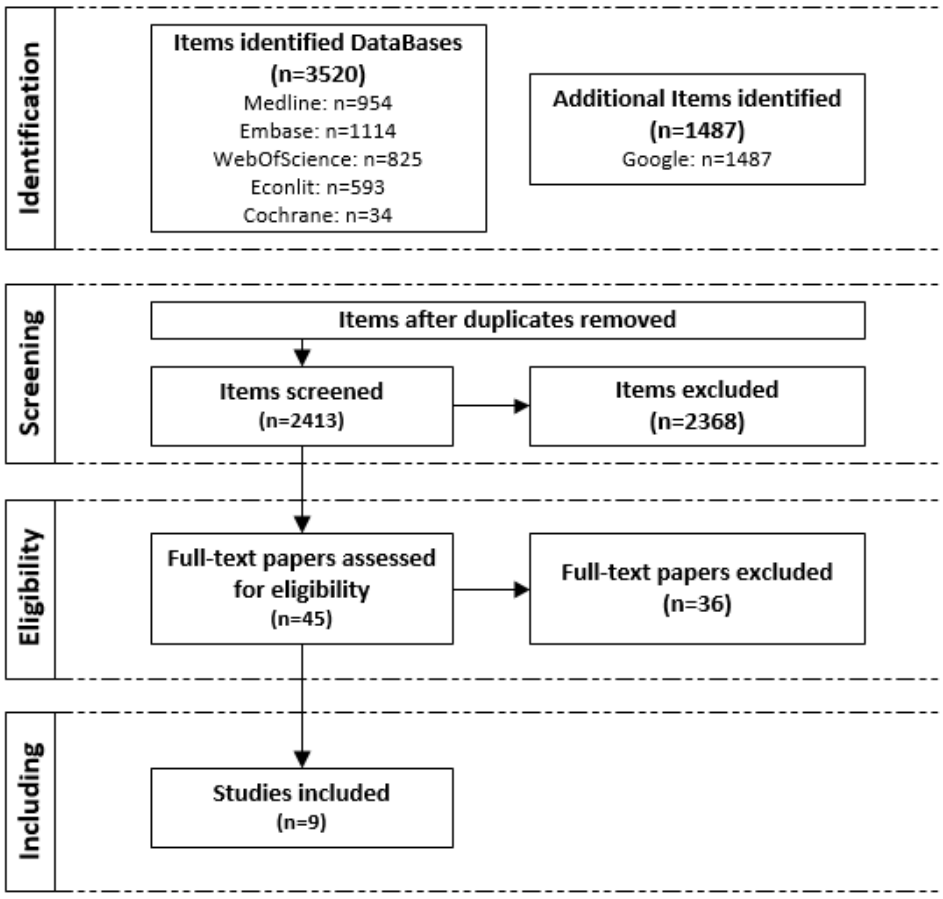

Fig 1 PRISMA (preferred reporting items for systematic reviews and meta-analyses) diagram

2.1.3 Data Extraction and Analysis

Data was extracted from the selected articles including: the year and place of the study, the aims and objectives of study (i.e. what is prioritized), the alternatives evaluated, the participants (i.e. the respondents of the weighting and scoring processes) and the criteria used in the analysis. Information about MCDA tool,

the MCDA techniques used (i.e., the weighting and scoring methods) and the software description presented in the included studies was also extracted.

2.2 Description of MCDA software identified from the systematic review

Each software tool found in the studies included in the systematic review was downloaded (latest version available to December 2018), installed and tested to identify the main technical features including the general features associated with MCDA software as well as specific considerations to health priority setting. Full versions of the MCDA software, where freely available, and trial versions otherwise were downloaded.

Based on previous studies [20,21], the following general characteristics were extracted including creation date, country, operating system required, web interface, available versions and prices. Technical aspects were also extracted including the type of MCDA technique; visualization (graphical interface for the inputs and results); sensitivity analysis (evaluation of the uncertainty impact on the final ranking); cluster analysis (evaluation of possible user groups, criteria or technologies); and availability of tutorials and/or manuals.

Moreover, considerations specifically relating to healthcare prioritisation were extracted such as whether the tool has capability to perform Value for Money (VfM) [22,23], to take into account the issues associated with the consideration of costs and opportunity costs in health care priority setting [19,24].

3. Results

3.1 Results of the systematic review of studies using MCDA software for priority setting

3.1.1 Literature Searches and sifting

A total of 5007 articles were identified in the searches, of which 2594 were duplicates. After the screening for titles and abstracts taking into account the inclusion and exclusion criteria, 45 papers were selected for full-text assessment. 36 articles were discarded, mainly because they were not related to health care (e.g. related to prioritization in veterinary medicine), or because they did not carry out a prioritization process or did not use an MCDA software tool. The results of the sifting are presented as PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) diagram in Figure 1.

3.1.2 Data Extraction

An overview of the nine included studies is presented in Table 1. The studies were from six countries (Canada, Colombia, Israel, New Zealand, United Kingdom [UK] and United States of America [USA]), in the period between 2012 and 2016. Three studies, by Madhavan et al [25–27], related to the same project. Table 1 presents summary of the data extracted, including the objective of study, the alternatives evaluated, the participants, the criteria, the MCDA software and the MCDA techniques used. These data are described in more detail below.

All the case studies had the purpose of ranking health technologies, two studies ranked a group of technologies made up of medicines and medical devices [28,29]; two studies prioritized vector-borne and zoonotic diseases [7,10]. The study by Airoldi et al. was focused on health programs [22]; while Castro et al. and Madhavan et al. carried out a prioritization of medicines and vaccines, respectively [25–27,30].

The participants in the MCDA were key stakeholders such as professionals or health experts, patients, providers, officials in the public health sector, representatives of patient organizations and academics. The general public was included as participants in some of the studies [22,28]. The number of participants had

a large dispersion from seven in Castro et al. [30] to more than 300 people in the study of Sullivan et al. [29]. Of the nine studies, only two had less than 50 participants.

The criteria used in the analyses mainly related to the following categories: health benefits (lives saved, life-prolongation benefit, quality-of-life gains, health before treatment, individual benefits), public health (health inequality reduction, social impact, lifestyle, social benefits, public health interest), economic (total costs, cost-effectiveness of intervention), environmental (influence of climate change) and epidemiological or demographical factors (number of potential patients, patient age).

Seven different software tools were identified : 1000minds [28,29], M-MACBETH [7], Socio Technical Allocation of Resources (STAR) [22], Strategic Multi-Attribute Ranking Tool (SMART) [25–27], Visual PROMETHEE [10], EVIDEM [30], and the Prioritisation Framework [31] developed by the Public Health England (PHE). Six studies related to MCDA software tools developed specifically to deal with specific problems of prioritization in health [22,25–27,30,31]. The other studies used existing MCDA frameworks/software for addressing health care prioritisation problems [7, 28, 29].

Different MCDA techniques were used in the software. Six techniques were identified: Potentially all pairwise rankings of all possible alternatives (PAPRIKA) [28,29], Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) [7], Additive version of multi-attribute utility method (MAUT) [25–27], Program budgeting and marginal analysis (PBMA) and Simple Additive Weighting (SAW) [22], Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [10] and SAW [30].

In general, the studies lacked a detailed description of the software characteristics. Only, three studies by Madhavan et al. [25–27] provided details regarding software design and implementation. Airoldi et al., Castro et al. and Sullivan et al. did not describe the features of the software tools used [22,29,30]. Golan et al., Cox et al. and Hongoh et al. only mentioned the version and website of the applications [7,10,28]. As such, each software was downloaded and tested to identify and describe their key features as presented in the next section.

Table 1 Studies included in the review

Paper	Golan et al. [28]	Cox et al. [7]	Airoldi et al. [22]	Madhavan et al. [25–27]	Hongoh et al. [10]	Castro et al. [30]	Sullivan et al. [29]
Year	2012	2013	2013	2012 – 2015	2016	2013	2016
Country	Israel - New Zealand	Canada	UK	USA	Canada	Colombia	New Zealand
Description	To present "The Value for Money Chart" a method for health technology prioritization based on value for money that makes possible the variables considered by decision-makers to be explicitly compared to the cost of each technology.	To develop and assess a method to prioritise infectious diseases in Canada using Multicriteria Decision Analysis.	To introduce and illustrate STAR (Socio-Technical Allocation of Resources) based on visual models, principles of Cost-Effective Analysis and Multi-criteria Decision Analysis to be used by health planners in their task of allocating fixed budgets.	To support technically a multicriteria framework for identifying and prioritizing new preventive technologies (vaccines) for their development.	To develop a multicriteria decision analysis approach to evaluate multi-stakeholder concerns around climate-sensitive infectious diseases priority setting in Quebec and Burkina Faso.	To test MCDA for systematic and more transparent resource-allocation decision-making in Colombia.	To report a methodology to determine the criteria and weights developed and validated in New Zealand that allows a broad participation of the population
Objective	To rank health technologies considering the concept of the value of money based on realistic data of the Israeli Basket Committee at period 2005-2008.	To rank nine diseases using two different software approaches, Microsoft Excel and M-MACBETH. There was not to explicitly compare the two methods.	To allocate a fixed budget among various candidate health programmes. In particular, how to best spend an incremental investment of £ 1 million in the National Health Service (NHS) in 2008.	To prioritize vaccines for research and development conducted with three user groups: the Public Health Agency of Canada (chlamydia and tuberculosis), New York State Department of Health (two existing rotavirus	To compare prioritization preferences between Quebec and Burkina to identify common aspects and reduce the impact of climate-sensitive infectious diseases on public health.	To appraise four technologies with a MCDA approach	To rank 14 health technologies using a discrete choice experiment and focus groups.

				vaccines, Rotateq and Rotarix), and the Serum Institute of India (dengue and respiratory syncytial virus).			
Alternatives evaluated	Technologies (15): Smoking cessation drugs, Taxotere, Herceptin, Elaprase, Visudyne, Left-ventricular assist devices, Statins, Pain relief, Revlimid, Dental care, Growth hormone, Avastin, Over-active bladder drugs, Fuzeon, Long-acting insulins, Contraceptives, Erbitux, Humira.	Diseases (14): Blastomycosis, Bluetongue, Chagas disease, Chikungunya, Cholera, Coccidioidomycosis, Dengue, Foot and Mouth disease, Giardiasis, Hantavirus Pulmonary Syndrome, Lyme disease, Rift Valley fever, Streptococcus pneumonia, West Nile virus.	Interventions (18): Pneumonia, Dementia services, Transient ischemic attack, Prison mental health, Obesity training, Workforce development, Psychological therapies, Child and Adolescent Mental Health Services, Prevention, Cardiac rehabilitation, Alcohol misuse services, Social inclusion, Palliative and end-of-life care, Obesity, Primary prevention, Access to dental care, Relocating; active treatment, Stroke emergency, Acute coronary heart disease.	Technologies: Hypothetical vaccines candidates for pneumococcal infection and used data from South Africa for the test case.	Diseases (4): Chikungunya, dengue, lymphatic filariasis, malaria and West Nile virus.	Technologies (4): Primary Prophilaxis for severe haemophilia A, zinc supply for diarrhoea prevention, anastrazole as first-line therapy for metastasic breast cancer and ticagrelor + acetylsalicylic acid for acute coronary syndrome.	Technologies (14): Statins, Service for Postnatal Depression, Hip Replacements, Methadone, Vaccine for Preventing Cervical Cancer, in vitro fertilization, positron emission tomography, Dialysis for End-stage Renal Disease, Abatacept, Antiretroviral Drugs for HIV, Imatinib, Hand Sanitizer use, Growth Hormone, Oral Drugs for Erectile Dysfunction

Participants	The survey was answered by a sample of 74 respondents (61 Israelis, 13 researchers from Canada), including professionals or researchers in healthcare, representatives of patients' organizations, general public [29].	64 experts were from academic, government and independent backgrounds	Around 100 people were involved, among which are: executive directors, facilitator, care clinicians, council representatives, voluntary sector representatives, nurses, patients, citizens, managers of the hospital and the ambulance service.	The number of participants in each group is not specified. Three teams were formed mainly by experts in disease spread modelling, policy research, and health economics; health officials, epidemiologists, etc.	Twenty-seven stakeholders participated in two focus groups, twelve in Quebec and fifteen in Burkina Faso.	Weighting: twelve local stakeholders (three academics, five researchers, three civil servants, and one senior hospital manager). Scoring: Seven participants.	The survey was answered by 322 people (response rate of 10%), 25 questions of classification by pairs per person on average. The participants included patients, providers and academics, divided into six groups
Criteria	8 criteria: Benefits: Number of potential patient, Lives saved, Life-prolongation Benefits, Quality-of-Life gains, Social or ethical benefits. Other factors: Total cost, Quality of evidence, X-factors	40 criteria grouped into 5 groups: Group A: Disease epidemiology Group B: Ability to monitor, treat and control disease Group C: Influence of climate change in Canada Group D: Burden of disease Group E: Economic and social impact	3 criteria to identify value: Health benefit per person, Health inequality reduction, Probability of success.	28 attributes arranged in eight categories (Health, Economic, Demographic, Public, Scientific and Business, Programmatic, Intangible values).	In total twenty criteria were classified into six categories: Public Health, Social Impact, Risk and Epidemiological, Animal and Environmental Health, Economic and Strategic and Operational	15 criteria, 13 from the EVIDEM framework and two more contextual criteria.	6 criteria: Health before treatment, Individual benefits, Patient age, Lifestyle, Social benefit, Treatment options
Tool Name	1000minds	Software M-MACBETH	Socio Technical Allocation of Resources (STAR)	Strategic Multi-Attribute Ranking Tool (SMART)	Visual PROMETHEE software	EVIDEM	1000minds

MCDA Technique	PAPRIKA	MACBETH	PBMA/SAW	MAUT	PROMETHEE	SAW	PAPRIKA
Weighting Method	Conjoint-analysis survey to derive relative weights for the criteria	Two different methods of criteria weighting were compared, one using fixed weighting values, the other using probability distributions to account for uncertainty and variation in expert opinion.	Rating method	The rank order centroid approximation. Swing weighting method.	100 points were distributed across all the criteria.	Ranking voting system to assign weights (Borda count), using 1 to 5 range used by the EVIDEM collaboration. The weights were normalized	Weights for the criteria and the levels within each criterion were derived by mathematical methods based on linear programming
Software Description (taken from the paper)	- 1000minds were co-invented by Hansen (Paper author), www.1000minds.com. - The Value for Money Chart: Incremental Benefit index (y-axis), Quality of evidence (bubble's size), Incremental cost (x-axis), any additional 'X-factors' (bubble's colour).	- It was developed a spreadsheet tool in Excel where were listed the criteria, these were implemented as predefined drop-down selection boxes. - M-MACBETH tool (version 2.3.0, www.m-macbeth.com, BANA consulting 2010).	Microsoft Excel.	MATLAB for algorithm development and testing, JAVA Servlets for the middleware, and Axure for visual prototyping and interface development. The preliminary database was managed using Microsoft SQL Server.	Visual PROMETHEE software (version 1.4.0.0) (VP Solutions software, Brussels, Belgium, http://www.promethee-gaia.net).	Microsoft Excel.	Paper does not present a description of the software

PAPRIKA Potentially all pairwise rankings of all possible alternatives, , *MACBETH* Measuring Attractiveness by a Categorical Based Evaluation Technique, *PBMA* Program Budgeting and Marginal Analysis, *MAUT* Multi-Attribute Utility Method, *PROMETHEE* Preference Ranking Organization Method for Enrichment Evaluations, *SAW* Simple Additive Weighting

3.2 Results of the description of MCDA software

The seven software identified from the systematic review were downloaded. Full versions were obtained for four software (SMART, STAR, EVIDEM, Prioritisation Framework) as these were freely available and trial versions were obtained for the other three software (1000minds, Visual PROMETHEE, M-MACBETH), as these required payment for accessing full versions. An overview of all the software is presented in Table 2. These software varied in terms of operating systems (including web interface), MCDA technique(s), visualization, and the capability to perform VfM and sensitivity analyses.

Three software were implemented in MS Excel (STAR, EVIDEM, Prioritisation Framework) while the other four were developed as stand-alone software (1000Minds, SMART, Visual PROMETHEE, M-MACBETH). 1000minds is developed as a web application, which allows remote participation and the access of results in real time. SMART was developed in MATLAB. The details of the underlying programming language of Visual PROMETHEE and M-MACBETH were not clear.

Each software implemented a single MCDA method. M-MACBETH uses pairwise comparison with interval scales [32]. 1000minds uses PAPRIKA (Potentially all pairwise rankings of all possible alternatives), which involves pairwise rankings of undominated pairs [33]. Visual PROMETHEE uses the PROMETHEE technique, an outranking approach based on thresholds of preference and indifference [34]. SMART software is based on MAUT [35], where the final ranking of vaccines is generated through a weighted average of the attributes (quantitative or qualitative) chosen by the users; the process to weight the attributes is carried out through the "swing weighting" method. STAR application implemented programme budgeting and marginal analysis (PBMA), in which a marginal analysis of the benefits (based on SAW) and the costs added of new interventions is carried out comparing the lost benefits by a possible disinvestment [36]. Finally, in EVIDEM a simple linear aggregation model is applied, using a list of criteria and pre-established rating scales for weights and scores [37].

In relation to visual interface, all software have modules for the inclusion of alternatives, criteria (EVIDEM and SMART with a predefined list of criteria), elicitation of weights and scores; as well as a final ranking of the interventions. Software tools that were developed as proprietary software (1000minds, SMART Vaccines, Visual PROMETHEE, M-MACBETH) showed advantages in terms of accessibility and by generating additional graphs and analyses. For example, Visual PROMETHEE includes GAIA plane, which is a principal component analysis on the MCDA allowing the visualisation of multidimensional problems.

Deterministic sensitivity analysis was implemented in 1000minds, Visual PROMETHEE, and M-MACBETH (e.g. allowing modifying the weights to analyse their impact in the final ranking). Prioritisation Framework has the capability to perform scenario analysis comparing different budgets. 1000minds and Visual PROMETHEE also have the capability to perform cluster analysis; the former allows the grouping of stakeholders and the latter the analysis of subgroups of criteria.

Two of the identified software allow VfM analysis: Golan et al. implemented it in 1000minds allowing the comparison of the PAPRIKA ranking with the costs of the alternatives, evidence quality and other factors [28]. In STAR toolkit, the VfM analysis is carried out in a graph where the benefit and the cost of each alternative are represented by means of right triangles [22].

Lastly, all the software tools have support or help material. Table 2 shows the information available from manuals, tutorials and guides for each program, including website links to the help material for each of these software (last accessed July 2019). Of the 9 included software, XXx software just included manuals as pdf or word documents, xxx software had an interactive online help and some had help function inbuilt within the software itself.

Table 2 Overview of the MCDA software tools found in the review

		1000minds	SMART Vaccines	Visual PROMETHEE	STAR toolkit (Health Foundation)	M-MACBETH	EVIDEM	PHE Prioritisation Framework
Creation date		2003	2012 – 2015	2010	2013	Early 90's	2006	2018
Country		New Zealand	USA	Belgium	UK	Portugal	Canada	England
Operating system required		Any operating system compatible with a web browser.	Windows (XP or above)	Windows (XP or above)	Compatible with Excel 97-2007	Windows (XP or above)	Excel 2003 and later versions	Excel 2003 and later versions
MCDA Technique		PAPRIKA	MAUT	PROMETHEE	PBMA/SAW	MACBETH	SAW	SAW
Visualization	**Input**	Configuration form criterion relevance and performance matrix. Question-form involving trade-offs between the criteria.	Combo box for population and disease options, scrollbars for weighting and scoring	A table where the alternatives, criteria, weights and their values are entered.	Excel table with list of interventions, benefit in numbers, feasibility of success, cost, intervention priority, etc.	Value tree where the criteria to be evaluated are entered, table of alternatives, performance matrix, scrollbars for scoring	A table in excel where the score and weighting values given by the evaluators are entered.	Spreadsheets: define scope, define criteria, weighting, gather evidence, scoring.
	Output	Preference values bar graph, radar chart of criterion weights, criterion value functions, rankings table, disaggregated tornado chart, bubble chart (four variables)	Ranking bar graph (criteria color-code), rankings table	Ranking table; diamond, network and rainbow graphs, Gaia plane, etc.	Chart benefit per person, value for money graph (triangles and bars), efficiency frontier graph	Sensitivity analysis XY graphic, robustness analysis table, scoring table, ranking table, among others	Dispersion and radar graphs referring to criteria weights score per criterion and criterion contribution.	Summary tables of the ranking and scenarios, final recommendation dashboard
Value for Money (VfM)		A bubble chart is used to represent VfM, the y-axis shows the benefit of each alternative in terms of a "PAPRIKA total score" and the x-axis illustrates the	No	No	VfM is represented in right triangles whose legs correspond to the benefits and costs of the intervention. With a greater gradient, the VfM is better.	No	No	No

	cost of each alternative. Additionally, the size and color of the bubbles reflect factors such as risk, evidence quality, strategic factors, etc.						
Sensitivity analysis	Tornado charts one-way sensitivity analysis to each alternative	No	Modules where it is possible to change the criteria weighting and evaluate the final score of the alternatives.	No	Graphically, the weight of each criterion can be changed one at a time and the others maintain their distribution proportionally to determine the impact on the final score.	No	Scenario Modelling to compare budget based on the potential scores and proportional (dis)investment across all programme areas.
Cluster analysis	Market segmentation using k-means clustering method	No	Subset of criteria for sensitivity analysis	No	No	No	No
Available versions / Prices (July 2019)	**Free:** 21-day trial **Paid version:** It is typically charged US$20,000 but the price could be proportional to the application and circumstances	Full version with no cost	The **Academic Edition** is free for all non-profit research and teaching use. The **Business Edition** can be used for any purpose. The price of the license is 1,250€.	Full version with no cost	**Demo:** Free **Academic:** 175€ **Professional:** 1750€ **Campus:** 1750€ **Corporate:** 17500€	Full version with no cost	Full version with no cost
Availability of tutorials and/or manuals	Information related to each section of the application as well	The software is designed to self-guide the user through the	The manual is available in pdf, epub and mobi formats on the	Documents for the use of the application in pdf format, a	The tool has a specific section to guide the user	On the developer's website you can find the tutorial, evidence matrix,	The tool provides guidance in each section.

	as demonstration models that are possible templates to work with: https://www.1000minds.com/about/how-it-works/decision-making-prioritization	prioritization process. For more information it is necessary to contact the developer at: https://www.nap.edu/smartvaccines/feedback.html	owner's website: http://www.promethee-gaia.net/vpb.html In the application, there is also a help section.	facilitator's guide, a training tool as well as a section for the online demonstration of the tool https://www.health.org.uk/funding-and-partnerships/programmes/star-a-tool-for-commissioners	through each section. http://m-macbeth.com/demo/	instructions for making adaptations and a guide to concepts and definitions. https://www.evidem.org/evidem-framework/	https://www.gov.uk/government/publications/the-prioritisation-framework-making-the-most-of-your-budget

4. Discussion

This article set out to provide a systematic review of the studies using MCDA software tools to support health prioritisation processes and to examine the MCDA software used for health care priority setting.

Whilst previous reviews on the use of MCDA in healthcare decision-making identified studies related to priority setting, they did not focus specifically on those that used MCDA software. For instance, Weernink et al. searched for studies that used a preference elicitation method in the context of Health Technology Assessment (HTA) and found only three studies that used MCDA for priority setting [38]. In the Marsh et al. review [14], of the 40 MCDA studies applied in the assessment of value of healthcare Interventions, 22 studies related to prioritization of interventions . Adunlin et al. also searched for publication patterns and topics where MCDA has been used and found eight publications on priority setting (12%) [15]. These reviews report that the majority of the included studies were bespoke analyses without the use of MCDA software.

To our knowledge, there has not been a systematic review on the use of multicriteria software in health priority setting and our study represents the first. Our review found only a few studies that used MCDA software in healthcare decision-making. Nine studies were identified in Canada, New Zealand, UK, USA, Israel, and Colombia which looked at the prioritisation of medicines, procedures, medical devices, diseases and/or health programs at a national level. From these nine studies, seven software were identified. EVIDEM, STAR, SMART and Prioritisation Framework provide free access to their full version, which were developed specifically to assess healthcare decisions. M-MACBETH, 1000minds and Visual PROMETHEE are general-purpose commercial software that have also been implemented in other fields [39]. In all the MCDA software identified, the inputs are used to define aspects such as criteria, weights, alternatives and scores; and the MCDA tools integrate these data, producing outputs such as graphs, tables, and reports.

The advantages suggested by the use of software in the studies include greater participation of stakeholders, capability to include higher number of criteria, the ability to perform sensitivity/scenario analyses and visual presentation of the results. Whilst the other advantages are useful, we suggest caution against using higher number of criteria and to some extent, the use of greater number of stakeholders as well.

In general, the use of MCDA software allow greater participation from stakeholders; ranging between 7 and 322 participants in those studies we identified in the review. The automatic generation of forms, the ability to handle large amount of information and possibility of responding through a web interface make it feasible to cater for many participants. However, appropriate caution needs to be taken to ensure that there is sufficient discussion between the stakeholders prior to preference elicitation as the true benefit of MCDA is the learning from the participatory process, not mechanistic implementation of the techniques [40].

Likewise, a higher number of decision criteria can be included in the analysis when using MCDA software. In in the studies included in our review, the number of decision criteria evaluated by the MCDA software range between 3 and 40. This is higher than the number of decision criteria reported in a previous review of MCDA studies (average of 8.2 criteria, ranging between 3 and 19), suggesting more criteria are included in studies using MCDA software compared to those using MCDA without the support of off-the-shelf software [14]. As such, caution needs to be taken to ensure that all the criteria are relevant to the problem when using the MCDA software rather than including every possible criterion. This is to avoid cognitive burden (even with the MCDA software there is substantive burden on the stakeholders for every additional criterion) and the associated risks such as the possibility of biased outputs.

All the software present the information visually to support the decision making and the exploration of data in an easy and quick manner to different stakeholders at different levels [41]. Regarding graphical interface of the analysed applications, Prioritisation Framework, EVIDEM and STAR were developed on an existing

platform (MS Excel), and as such are limited in their presentation of results due to the constraints of the underlying platform (MS Excel). In contrast, the other proprietary software (i.e. 1000minds, Visual PROMETHEE and M-MACBETH), which were developed as bespoke applications, offer more variety in the graphic options for results interpretation as well as customized reports depending on the problem proposed.

In our review, only M-MACBETH, 1000minds and Visual PROMETHEE allow a parametric sensitivity analysis, and the results are presented using graphs, tornado charts or stability intervals. Sensitivity analysis is considered important in allowing the decision maker explore the reasons for the discrepancies in MCDA model results with their expectations [42]. In addition to sensitivity analyses, there are other types of uncertainty: stochastic, heterogeneous and structural uncertainty [43], which are not included in any of the MCDA software that we examined. These analyses are not always performed in multi-criteria studies in health; as reported in the review by Marsh et al.[14] where only 50% of the studies reported some type of uncertainty analysis. For health priority setting, further software or improvements in existing software is required to consider uncertainty in a robust way.

Given the health care priority setting is about resource allocation, consideration of costs is necessary. However, many of the software do not consider cost aspects or budgets explicitly. VfM analysis offers a way to appraise them, contrasting overall MCDA scores with the costs of the alternatives to identify the rank order of technologies in terms of value for money (i.e. which technologies provide the most value for the least cost) [44]. In our review, only two of the identified software allow VfM analysis: 1000minds and STAR. Consideration of opportunity costs in MCDA is an important issue and has been highlighted by many researchers [19,23,45]. It is recommended that all health priority setting software should include the ability to perform VfM analyses to include an explicit consideration of costs.

Our review has some limitations. Although it was carried out through a systematic procedure and consulting multiple databases, the list is unlikely to be exhaustive. Due to sensitive nature of priority setting projects at a national or local level, there may be studies that are not published in indexed journals. As such, there may be other relevant studies (and software) in the non-indexed grey literature that were not included in our review. Furthermore, studies that did not mention priority or prioritization in their title or abstract may have been missed. However, we performed reference checking and citation searching of the included studies to ensure the inclusion of all relevant studies that used MCDA software for priority setting in health care.

The review was also limited by the information presented in the published studies and the information in the MCDA software tools. The included studies did not delve into the description of aspects such as the selection of the software tool, the characteristics and performance of the software, and the challenges of its implementation. As all the tested software only implement a single multi-criteria technique, the appropriate approach should be determined first because software packages rarely allow the choice of multiple MCDA methods [42]. In addition, some extra features of commercial software tools were not described because we did not have access to the full version.

Our review focussed on MCDA software that were used in health care priority setting. However, there are many MCDA software that are used in other fields, which could prove useful for health care priority setting. For an overview of MCDA tools in other fields, and to assess their usefulness for healthcare, we point the readers towards the key studies that review MCDA software [18,46–49]. These include the study of Ishizaka et al. that provides an assessment of nine MCDA methods and illustrates each method with freely available software [18]; Li et al. identified a set of ten MCDA methods and proposed a framework for MCDA software selection [46]; Weistroffer et al. describe and categorise 69 MCDA software based on the type of the decision problem to be resolved, the decision context, and the technology platform required by the software [47]; 23 multi-criteria decision analysis software tools were analysed by Mustajoki et al. in terms of

their applicability to support environmental planning processes [48]; and finally, Baizyldayeva et al. compared 10 decision-making software packages and provide recommendations on implementing them in Kazakhstan [49].

5. Conclusions

We found that the use of multi criteria software yields advantages for the development of prioritization processes in health care and offer the possibility of adopting different MCDA methods. They also allow the inclusion of several types of stakeholders with the ability to analyse a greater number of alternatives and/or criteria, and perform sensitivity analyses. However, this field is still developing with only a few studies that have implemented multi-criteria software in health care priority setting. There are software available but those that offer users more functionalities of analysis, visualization, and reports often require a license payment.

6. Availability of data and materials.

All data analysed or generated during this study are included in this article.

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Conflict of interest Alexander Moreno is a PhD candidate at the Universidad Nacional de Colombia. He received a doctoral grant. However, he has no conflicts of interest. Thaison Tong is a Research Associate in Health Economics and Decision Sciences at the School of Health and Related Research, University of Sheffield. He has no financial or non-financial conflicts. Praveen Thokala is a Senior Research Fellow in Health Economics and Decision Sciences at the School of Health and Related Research, University of Sheffield. He has no financial or non-financial conflicts.

Appendix 1

See Table 3

Table 3 Search strategies

Database	N	Search strategies	Results
Cochrane Database of Systematic Reviews	1	MeSH descriptor: [Software] explode all trees	3154
	2	tool* or program* or application*	1571104
	3	#1 or #2	1571103
	4	MeSH descriptor: [Delivery of Health Care] explode all trees	43273
	5	Health*	375049
	6	#4 or #5	390637

	7	prioritization algorithm or "prioritization analysis" or "prioritization approach" or "prioritization based" or "prioritization capacity" or "prioritization criteria" or "prioritization decision making" or "prioritization decisions" or "prioritization efforts" or "prioritization framework" or "prioritization matrix" or "prioritization method" or "prioritization methodology" or "prioritization methods" or "prioritization procedure" or "prioritization process" or "prioritization processes" or "prioritization project" or "prioritization protocol" or "prioritization rule" or "prioritization scheme" or "prioritization schemes" or "prioritization skills" or "prioritization strategies" or "prioritization study" or "prioritization system" or "prioritization tool" or "prioritization tools" or "prioritizations" or "prioritized research agenda" or "prioritized selection" or "prioritized world agenda" or "priority setting"	170
	8	#3 and #6 and #7	**34**
Econlit	1	Software or tool* or program* or application	343369
	2	Priorit* OR Resource allocation	84345
	3	Health*	159704
	4	#3 AND #2 AND #1	**593**
Embase	1	SOFTWARE/	32145
	2	(tool* or program* or application*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	2973371
	3	1 or 2	3075578
	4	"Delivery of Health Care"/	170489
	5	(Health or healthcare).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	3725876
	6	4 or 5	3725876
	7	("prioritization algorithm" or "prioritization analysis" or "prioritization approach" or "prioritization based" or "prioritization capacity" or "prioritization criteria" or "prioritization decision making" or "prioritization decisions" or "prioritization efforts" or "prioritization framework" or "prioritization matrix" or "prioritization method" or "prioritization methodology" or "prioritization methods" or "prioritization procedure" or "prioritization process" or "prioritization processes" or "prioritization project" or "prioritization protocol" or "prioritization rule" or "prioritization scheme" or "prioritization schemes" or "prioritization skills" or "prioritization strategies" or "prioritization study" or "prioritization system" or	3568

		"prioritization tool" or "prioritization tools" or "prioritizations" or "prioritized research agenda" or "prioritized selection" or "prioritized world agenda" or "priority setting").mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	
	8	3 and 6 and 7	**1114**
Medline	1	SOFTWARE/	103406
	2	(tool* or program* or application*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	2305919
	3	1 or 2	2421801
	4	"Delivery of Health Care"/	85385
	5	(Health or healthcare).mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	2654938
	6	4 or 5	2654938
	7	("prioritization algorithm" or "prioritization analysis" or "prioritization approach" or "prioritization based" or "prioritization capacity" or "prioritization criteria" or "prioritization decision making" or "prioritization decisions" or "prioritization efforts" or "prioritization framework" or "prioritization matrix" or "prioritization method" or "prioritization methodology" or "prioritization methods" or "prioritization procedure" or "prioritization process" or "prioritization processes" or "prioritization project" or "prioritization protocol" or "prioritization rule" or "prioritization scheme" or "prioritization schemes" or "prioritization skills" or "prioritization strategies" or "prioritization study" or "prioritization system" or "prioritization tool" or "prioritization tools" or "prioritizations" or "prioritized research agenda" or "prioritized selection" or "prioritized world agenda" or "priority setting").mp. [mp=title, abstract, original title, name of substance word, subject heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	3074
	8	3 and 6 and 7	**954**
Web of Science	1	TI=(Software or tool* or program* or application*)	3500827
	2	TI=(Priorit* OR Resource allocation)	110568
	3	TS=(Health*)	7401584
	4	#3 AND #2 AND #1	**825**

References

1. Defechereux T, Paolucci F, Mirelman A, Youngkong S, Botten G, Hagen TP, et al. Health care priority setting in Norway a multicriteria decision analysis. BMC Health Serv Res. 2012;12:39.
2. Sabik LM, Lie RK. Priority setting in health care: Lessons from the experiences of eight countries. Int J Equity Health. 2008;7:4.
3. Nunes R, Rego G. Priority setting in health care: a complementary approach. Health Care Anal. 2014;22(3):292–303.
4. Baltussen R, Jansen MPM, Bijlmakers L, Grutters J, Kluytmans A, Reuzel RP, et al. Value Assessment Frameworks for HTA Agencies: The Organization of Evidence-Informed Deliberative Processes. Value Health. 2017;20(2):256–60.
5. Giedion Ú, Villar M, Ávila A. Los sistemas de salud en Latinoamérica y el papel del seguro privado. 2010;
6. Hall W, Williams I, Smith N, Gold M, Coast J, Kapiriri L, et al. Past, present and future challenges in health care priority setting. J Health Organ Manag. 2018;32(3):444–62.
7. Cox R, Sanchez J, Revie CW. Multi-Criteria Decision Analysis Tools for Prioritising Emerging or Re-Emerging Infectious Diseases Associated with Climate Change in Canada. Cameron DW, editor. PLoS One. 2013;8(8):e68338.
8. Baltussen R. Priority setting of public spending in developing countries: Do not try to do everything for everybody. Health Policy (New York). 2006;78(2–3):149–56.
9. Mullen PM. Quantifying priorities in healthcare: transparency or illusion? Heal Serv Manag Res. 2004;17(1):47–58.
10. Hongoh V, Michel P, Gosselin P, … KS-I journal of, 2016 U. Multi-stakeholder decision aid for improved prioritization of the public health impact of climate sensitive infectious diseases. mdpi.com.
11. Angelis A, Kanavos P. Value-Based Assessment of New Medical Technologies: Towards a Robust Methodological Framework for the Application of Multiple Criteria Decision Analysis in the Context of Health Technology Assessment. Pharmacoeconomics. 2016;34(5):435–46.
12. N. H. S. Confederation. Priority Setting: An Overview. Prim Care Trust Netw. 2007;
13. Belton V, Stewart T. Multiple criteria decision analysis: an integrated approach [Internet]. 2002 [2019 Nov 10].
14. Marsh K, Lanitis T, Neasham D, Orfanos P, Caro J. Assessing the value of healthcare interventions using multi-criteria decision analysis: a review of the literature. Pharmacoeconomics. 2014;32(4):345–65.
15. Adunlin G, Diaby V, Xiao H. Application of multicriteria decision analysis in health care: a systematic review and bibliometric analysis. Health Expect. 2015;18(6):1894–905.
16. Ghandour R, Shoaibi A, Khatib R, Abu Rmeileh N, Unal B, Sözmen K, et al. Priority setting for the prevention and control of cardiovascular diseases: multi-criteria decision analysis in four eastern Mediterranean countries. Int J Public Health. 2015;60 Suppl 1(S1):S73-81.
17. Kosherbayeva L, Hailey D, Kurakbaev K, Tabarov A, Kumar A, Gutzskaya G, et al. A process of prioritizing topics for health technology assessment in kazakhstan. Int J Technol Assess Health Care.

2016;32(3):147–51.

18. Ishizaka A, Nemery P. Multi-criteria decision analysis: methods and software. 2013;

19. Claxton K. Three questions to ask when examining MCDA. Vol. 1, Value Outcomes Spotlight. 2015. 18–20 p.

20. Mustajoki J, Marttunen M. Comparison of Multi-Criteria Decision Analytical Software-Searching for ideas for developing a new EIA-specific multi-criteria software. 2013;

21. Sengupta R, Gupta A, Dutta J. Decision sciences: theory and practice. 2016;

22. Airoldi M, Morton A, Smith JAE, Bevan G. STAR--people-powered prioritization: a 21st-century solution to allocation headaches. Med Decis Making. 2014;34(8):965–75.

23. Thokala P, Ochalek J, Leech AA, Tong T. Cost-Effectiveness Thresholds: the Past, the Present and the Future. Pharmacoeconomics. 2018;36(5):509–22.

24. Sculpher M, Claxton K, Pearson SD. Developing a Value Framework: The Need to Reflect the Opportunity Costs of Funding Decisions. Value Heal. 2017;20(2):234–9.

25. Madharan G, Sangha K, Phelps C, Fryback D, Lieu T. Ranking vaccines: a prioritization framework: phase I: demonstration of concept and a software blueprint. Washington, D.C.: The National Academies Press; 2012.

26. Madhavan G, Sangha K, Phelps C, Fryback D. Ranking vaccines: a prioritization software tool: phase II: prototype of a decision-support system. Washington, D.C.: The National Academies Press; 2013. 160 p.

27. Madhavan G, Phelps C, Rappuoli R, Martinez RM, King L, For C on I and PNPV, et al. Ranking Vaccines: Applications of a Prioritization Software Tool: Phase III: Use Case Studies and Data Framework. Washington, D.C.: The National Academies Press; 2015.

28. Golan O, Hansen P. Which health technologies should be funded? A prioritization framework based explicitly on value for money. Isr J Health Policy Res. 2012;1(1):44.

29. Sullivan T, Hansen P. Determining Criteria and Weights for Prioritizing Health Technologies Based on the Preferences of the General Population: A New Zealand Pilot Study. Value Health. 2017;20(4):679–86.

30. Castro Jaramillo HE, Goetghebeur M, Moreno-Mattar O. Testing multi-criteria decision analysis for more transparent resource-allocation decision making in Colombia. Int J Technol Assess Health Care. 2016;32(4):307–14.

31. Public Health England. The Prioritisation Framework: making the most of your budget [Internet]. 2018 [2019 Mar 19].

32. Bana e Costa CA, de Corte J-M, Vansnick J-C. MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). In: Wiley Encyclopedia of Operations Research and Management Science. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2011.

33. Hansen P, Ombler F. A new method for scoring additive multi-attribute value models using pairwise rankings of alternatives. J Multi-Criteria Decis Anal. 2008;15(3–4):87–107.

34. Brans J, Science PV-M, 1985 U. Preference ranking organization method for enrichment evaluations. difusion.ulb.ac.be.

35. Keeney RL, Raiffa H. Decisions with multiple objectives : preferences and value tradeoffs. Cambridge University Press; 1993. 569 p.

36. Pole JD. Programmes, priorities, and budgets. Br J Prev Soc Med. 1974;28(3):191–5.

37. Abdullah L, International CA-, 2014 U. Simple additive weighting methods of multi criteria decision making and applications: A decade review. Adv Institutes Converg ….

38. Weernink MGM, Janus SIM, van Til JA, Raisch DW, van Manen JG, IJzerman MJ. A Systematic Review to Identify the Use of Preference Elicitation Methods in Healthcare Decision Making. Pharmaceut Med. 2014;28(4):175–85.

39. Weistroffer HR, Li Y. Multiple Criteria Decision Analysis Software. In Springer, New York, NY; 2016. p. 1301–41.

40. Thokala P, Madhavan G. Stakeholder involvement in Multi-Criteria Decision Analysis. Cost Eff Resour Alloc. 2018;16(S1):0.

41. Sacha D, Stoffel A, Stoffel F, … BK-I transactions on, 2014 U. Knowledge generation model for visual analytics. ieeexplore.ieee.org.

42. Marsh K, IJzerman M, Thokala P, Baltussen R, Boysen M, Kaló Z, et al. Multiple Criteria Decision Analysis for Health Care Decision Making—Emerging Good Practices: Report 2 of the ISPOR MCDA Emerging Good Practices Task Force. Value Heal. 2016;19(2):125–37.

43. Broekhuizen H, Groothuis-Oudshoorn CGM, van Til JA, Hummel JM, IJzerman MJ. A review and classification of approaches for dealing with uncertainty in multi-criteria decision analysis for healthcare decisions. Pharmacoeconomics. 2015;33(5):445–55.

44. Foundation PS-LTH, 2009 U. Measuring value for money in healthcare: concepts and tools. pdfs.semanticscholar.org.

45. Marsh K, Thokala P, Youngkong S, Chalkidou K. Incorporating MCDA into HTA: challenges and potential solutions, with a focus on lower income settings. Cost Eff Resour Alloc. 2018;16(S1):43.

46. Li Y, Thomas MA. A multiple criteria decision analysis (MCDA) software selection framework [Internet]. Proceedings of the Annual Hawaii International Conference on System Sciences. IEEE; 2014 [2019 Nov 12]. p. 1084–94.

47. Weistroffer HR, Li Y. Multiple criteria decision analysis software. Int Ser Oper Res Manag Sci. 2016;233:1301–41.

48. Mustajoki J, Marttunen M. Comparison of multi-criteria decision analytical software for supporting environmental planning processes. Environ Model Softw. 2017;93:78–91.

49. Baizyldayeva U, Vlasov O, Kuandykov AA, Akhmetov TB. Multi-Criteria decision support systems. Comparative analysis. Middle East J Sci Res. 2013;16(12):1725–30.