

JMcDM: A Julia package for multiple-criteria decision-making tools

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Abstract

JMcDM is a *Julia* package that implements some leading multiple-criteria decision making tools for both researchers and developers. *Julia*'s REPL is well suited for researchers to perform their analysis using different methods and compare their results. The package also provides the necessary infrastructure and utility functions for writing recently published methods. The proposed package has brought MCDA tools to a relatively new language such as *Julia* with its significant performance promises. The methods developed in the package are also designed to be familiar to users who previously used *R* and *Python* languages. The paper presents the basics of the design, example usage, and code snippets.

Keywords: julia, multiple-criteria decision-making, outranking

Required Metadata

Current code version

Nr.	Code metadata description	Please fill in this column
C1	Current code version	v0.1.7
C2	Permanent link to code/repository used for this code version	https://github.com/jbytecode/JMcDM
C3	Code Ocean compute capsule	
C4	Legal Code License	MIT
C5	Code versioning system used	git
C6	Software code languages, tools, and services used	Julia
C7	Compilation requirements, operating environments & dependencies	Julia 1.4
C8	If available Link to developer documentation/manual	https://jbytecode.github.io/JMcDM/docs/build
C9	Support email for questions	mhsatman@istanbul.edu.tr

Table 1: Code metadata (mandatory)

1. Motivation and significance

The one-dimensional array a is in ascending order if and only if $a_i \leq a_{i+1}$ where $i = 1, 2, \dots, n - 1$, and n is the length of array. In other terms, the process of ordering numbers requires the logical \leq operator to be perfectly defined. Since the operator \leq is not defined for any set of points in higher dimensions, \mathbb{R}^p for $p \geq 2$, there is not a unique ordering of points.

In multi-dimensional case, the binary domination operator \succ applied on points a and b , $a \succ b$, is true iif each item in a is not worse than the

correspoing item in b and at least one item is better than the corresponding item in b [1]. On the other hand, the more relaxed operator \succeq returns true if each item in a is as good as the corresponding item in b [2]. Several outranking methdods in MCDA (Multiple-Criteria Decision Analysis) define a unique ranking mechanism to select the best alternative among others.

Suppose a decision process has n alternatives and m criteria which are either to be maximized or minimized. Each single criterion has a weight $0 \leq w_i \leq 1$ where $\sum_i^m w_i = 1$. f_i is either maximum or minimum. $g_j(\cdot)$ is evolution function and it is taken as $g_j(x) = x$ in many methods. A multiple criteria decision problem can be represented using the decision table

Criteria	C_1	C_2	\dots	C_m
Weights	w_1	w_2	\dots	w_m
Functions	f_1	f_2	\dots	f_m
A_1	$g_1(A_1)$	$g_2(A_1)$	\dots	$g_m(S_A)$
A_2	$g_1(A_2)$	$g_2(A_2)$	\dots	$g_m(A_2)$
\vdots	\vdots	\vdots	\ddots	\vdots
A_n	$g_1(A_n)$	$g_2(A_n)$	\dots	$g_m(A_n)$

Table 2: A decision matrix in general form

without loss of generality. When A_1, A_2, \dots, A_n are alternatives and C_1, C_2, \dots, C_m are different situations of a single criterion then the decision problem is said to be single criterion decision problem. If A_i and C_j are strategies of two game players then $g_j(A_i)$ is the gain of the row player when she selects the strategy i and the column player selects the strategy C_j .

MCDA is used in material selection [3, 4], supplier selection [5, 6], personnel selection [7], inventory classification [8], service provider selection [9, 10, 11, 12], strategy selection [13, 14, 15], location selection [16, 17],

project selection [18, 19, 20], performance evaluation [21, 22, 23], risk evaluation [24, 25], allocation problems [6, 26, 27], and site selection [28, 29, 30] problems in the literature.

Multiple-criteria decision-making (MCDM) tools provide several algorithms for ordering or selecting alternatives and/or determining the weights when there is uncertainty. Although some algorithms are suitable for hand calculations, a computer software is often required. *PyTOPS* is a Python tool for TOPSIS [31]. *Super Decisions* is a software package which is mainly focused on AHP (Analytic Hierarchy Process) and ANP (Analytic Network Process) [32]. *Visual Promethee* implements Promethee method on Windows platforms [33]. *M-BACBETH* is an other commercial software product that implements MACBETH with an easy to use GUI. [34]. *Sanna* is a standard MS Excel add-in application that supports several basic methods for multi-criteria evaluation of alternatives (WSA, TOPSIS, ELECTRE I and III, PROMETHEE I and II, MAPPAC and ORESTE) [35]. *DEAFrontier* software requires an Excel add-in that can solve up to 50 DMUs with unlimited number of inputs and outputs (subject to the capacity of the standard MS Excel Solver) [36].

JMcDM is designed to provide a developer-friendly library for solving multiple-criteria decision problems in *Julia* [37]. Since *Julia* is a dynamic language, it is also useful for researchers that familiar with REPL environments. The package includes multi-criteria decision methods as well as a game solver for zero-sum games, and methods for single criterion methods.

2. Software description

51 2.1. Software Architecture

52 *JMcDM* provides a framework for performing multi-criteria decision anal-
53 ysis as well as it includes utility functions for development of new methods.
54 Each single MCDM method returns an object in subtype of `MCDMResult`
55 which is defined as

```
56 abstract type MCDMResult end
```

57 and it is used to derive new return types. For instance, the `topsis()` function
58 always returns a `TopsisResult` object which is defined as

```
59 struct TopsisResult <: MCDMResult  
60     decisionMatrix::DataFrame  
61     weights::Array{Float64,1}  
62     normalizedDecisionMatrix::DataFrame  
63     normalizedWeightedDecisionMatrix::DataFrame  
64     bestIndex::Int64  
65     scores::Array{Float64,1}  
66 end
```

67 and holds many outputs in a single `struct`. Function definitions are also
68 similar but they may differ depending on the requirements of algorithms.
69 For instance the function `topsis` is defined as

```
70 function topsis(  
71     decisionMat::DataFrame,  
72     weights::Array{Float64,1},  
73     fns::Array{Function,1})::TopsisResult
```

74 where `decisionMat` is the decision matrix, `weights` are weights of criteria,
75 and `fns` is an array of functions (either `minimum` or `maximum`) that determine
76 the optimization directions.

77 The package is registered in *Julia* package repository and it is available
78 for downloading and installing using *Julia*'s package manager.

```
79 julia> using Pkg  
80 julia> Pkg.add("JMcDM")
```

81 and

```
82 julia> ]  
83 (@v1.5) pkg> add JMcDM
```

84 present two distinct ways of downloading and installing the package.

85 2.2. *Software Functionalities*

86 The package implements methods for TOPSIS¹ [38], ELECTRE²[39],
87 PROMETHEE³ [40], DEMATEL⁴ [41], MOORA⁵ [42], VIKOR⁶ [43, 44],
88 AHP⁷ [45], GRA⁸ [46], NDS⁹ [1], SAW¹⁰ [47, 48], ARAS¹¹ [49], WPM¹² [48],

¹Technique for Order Preference by Similarity to Ideal Solutions

²Elimination and Choice Translating Reality

³Preference Ranking Organization METHod for Enrichment of Evaluations

⁴The Decision Making Trial and Evaluation Laboratory

⁵Multi-Objective Optimization By Ratio Analysis

⁶VlseKriterijumska Optimizacija I Kaompromisno Resenje in Serbian

⁷Analytic Hierarchy Process

⁸Grey Relational Analysis

⁹Non-dominated Sorting

¹⁰Simple Additive Weighting

¹¹Additive Ratio Assessment

¹²Weighted Product Model

WASPAS¹³ [50], EDAS¹⁴ [8], MARCOS¹⁵ [5], MABAC¹⁶ [51], MAIRCA¹⁷ [52], COPRAS¹⁸ [53], COCOSO¹⁹ [54], CODAS²⁰ [55], CRITIC²¹ [56], and Entropy[57] for multiple-criteria tools. The package also performs DEA for Data Envelopment Analysis [58] and includes a method for zero-sum game solver. The full set of other tools and utility functions are listed and documented in the source code as well as in the online documentation.

2.3. Sample code snippets analysis

Suppose a decision problem is given in Table 3.

Criteria	Age	Size	Price	Distance	Population
Weights	0.35	0.15	0.25	0.20	0.05
Functions	min	max	min	min	max
A_1	6	140	150000	950	1500
A_2	4	90	100000	1500	2000
A_3	12	140	75000	550	1100

Table 3: Decision matrix

In this sample problem, a decision maker is subject to select an apartment by considering age of the building, size (in m^2 s), price (in \$), distance to city centre (in ms), and nearby population. The data can be entered as a two-dimensional array (matrix) or as a DataFrame object:

¹³Weighted Aggregated Sum Product ASsessment

¹⁴Evaluation based on Distance from Average Solution

¹⁵Measurement Alternatives and Ranking according to COMpromise Solution

¹⁶Multi-Attributive Border Approximation area Comparison

¹⁷Multi Attributive Ideal-Real Comparative Analysis

¹⁸Complex PROportional ASsessment

¹⁹Combined Compromise Solution

²⁰COmbinative Distance-based ASsessment

²¹CRiteria Importance Through Intercriteria Correlation

```
101 julia> using JMCDM, DataFrames
```

```
102 julia> df = DataFrame(
```

```
103 :age      => [6.0, 4, 12],
```

```
104 :size     => [140.0, 90, 140],
```

```
105 :price    => [150000.0, 100000, 75000],
```

```
106 :distance => [950.0, 1500, 550],
```

```
107 :population => [1500.0, 2000, 1100]);
```

108 The weight vector **w**, vector of directions **fns**, and **topsis()** function call
109 can be performed using the *Julia* REPL.

```
110 julia> w = [0.35, 0.15, 0.25, 0.20, 0.05];
```

```
111 julia> fns = makeminmax([minimum, maximum, minimum, minimum, maximum]);
```

```
112 julia> result = topsis(df, w, fns);
```

```
113 julia> result.scores
```

```
114 3-element Array{Float64,1}:
```

```
115 0.5854753145549456
```

```
116 0.6517997936899308
```

```
117 0.41850223305822903
```

```
118
```

```
119 julia> result.bestIndex
```

```
120 2
```

121 In the output above, it is shown that the alternative A_2 has a score of 0.65179
122 and it is selected as the best. The same analysis can be performed using
123 **saw()** for the method of Simple Additive Weighting

```
124 julia> result = saw(df, w, fns);
```

```
125 julia> result.bestIndex
```

```
126 2
```


127 as well as using `wpm` for the method of Weighted Product Method

```
128 julia> result = wpm(df, w, fns);
```

```
129 julia> result.bestIndex
```

```
130 2
```

131 For any method, `?methodname` shows the documentation as in the same way
132 in other *Julia* packages.

133 2.3.1. Game Solver

134 A two-player zero-sum game is not a multi-criteria decision method. On
135 the other hand, assuming the column player's choices are natural states for
136 the row player, the game matrix represents gains or costs for the row player
137 depending on the alternative she plays. Table 4 represents the gains of the
138 row player for a Rock & Paper & Scissors game. Each time the game is
139 played, the winner takes 1 point.

	Rock	Paper	Scissors
Rock	0	-1	1
Paper	1	0	-1
Scissors	-1	1	0

Table 4: Game matrix for the Rock & Paper & Scissors game

140 Table 4 shows that the row player wins the game if she selects **Rock** and
141 the column player selects **Scissors**. Similarly, she loses the game if she
142 selects **Scissors** and the column player selects **Rock**. A tie has a zero gain
143 for both players. The problem is selecting the best strategy for the row
144 player. *JMcDM* implements the `game()` method for calculating value and
145 the best strategy of this kind of games. The code snippet below represents
146 the problem.

```

147 julia> mat = [0 -1 1; 1 0 -1; -1 1 0];
148 julia> dm = makeDecisionMatrix(mat);
149 julia> result = game(dm);

```

150 The `makeDecisionMatrix()` method returns a modified copy of the matrix
 151 `mat` as the minimum value of the new matrix is non-negative. The function
 152 `game()` returns a `GameResult` object which holds the value of the game and
 153 the probabilities of the alternatives for the row player.

```

154 julia> result.value
155 0.0
156 julia> result.row_player_probabilities
157 3-element Array{Float64,1}:
158 0.3333333333333333
159 0.3333333333333337
160 0.3333333333333333

```

161 It is shown that the value of the game is zero and the row player should select
 162 the alternatives with equal probability of $\frac{1}{3}$ in each iteration.

163 **3. Illustrative Examples**

164 Since *JMcDM* is designed as a software library and for REPL use, it does
 165 not implement a significant user interface. However, the `summary()` function
 166 provides a useful way to perform a list of methods and it returns a text based
 167 result to compare results.

```

168 julia> methods1 = [:topsis, :electre, :vikor,
169                  :moora, :cocoso, :wpm, :waspas];
170 julia> result1 = summary(df, w, fns, methods1);

```

```
julia> result1
```

3x7 DataFrame

Row	topsis	electre	cocoso	moora	vikor	wpm	waspas
	String	String	String	String	String	String	String
1			✓	✓	✓		
2	✓	✓				✓	✓
3		✓					

Figure 1: Results of TOPSIS, ELECTRE, VIKOR, MOORA, COCOSO, WPM, and WASPAS

Figure 1 represents the output of the `summary()` call for methods TOPSIS, ELECTRE, VIKOR, MOORA, COCOSO, WPM, and WASPAS, respectively.

```
julia> methods2 = [:aras, :saw, :edas, :marcos,
                  :mabac, :mairca, :grey];
julia> result2 = summary(df, w, fns, methods2);
```

Figure 2 represents the output of the `summary()` call for methods ARAS, SAW, EDAS, MARCOS, MABAC, MAIRCA, and GRA, respectively. Figure 1 and Figure 2 also show the necessity of using more than one decision-making tool as they produce different results for the same analysis.

4. Impact

JMcDM provides a moderate number of MCDA tools and utility functions for developing new methods as well as performing decision analysis using a single function call for each method. A researcher can easily perform sequential analysis by changing the problem parameters and can compare results of many tools. Existing software packages are mainly focused on providing a small subset of methods. *JMcDM* is an all-in-one solution and has

```
julia> result2
```

3x7 DataFrame

Row	grey	aras	saw	edas	marcos	mabac	mairca
	String	String	String	String	String	String	String
1							
2		✓	✓	✓	✓		
3	✓					✓	✓

Figure 2: Results of ARAS, SAW, EDAS, MARCOS, MABAC, MAIRCA, and GRA

188 potential for increasing user productivity. Seeing the different results pro-
 189 duced by the methods together also helps to discover which parameters the
 190 research is more sensitive to and the reasons for them.

191 5. Conclusions

192 Multiple-criteria decision-making tools are used in various disciplines in
 193 the literature. Since it is difficult to compute these tools manually, many soft-
 194 ware packages and programs have been developed. However, these packages
 195 include a selected subset of methods. *JMcDM* is a *Julia* package that con-
 196 tains a significant amount of tools in the literature. Implementations of these
 197 tools are straightforward to use in *Julia* REPL for researchers. *JMcDM* also
 198 provides the necessary infrastructure for the development of new methods in
 199 the literature with its utility functions, comprehensive documentation, and
 200 unit tests compiled from many text books. The proposed package has also
 201 brought MCDA tools to a relatively new language such as *Julia* with signif-
 202 icant performance promises. The methods in the package are also designed
 203 to be familiar to users who previously used R and Python languages.

204 **6. Conflict of Interest**

205 We wish to confirm that there are no known conflicts of interest associated
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