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 comparing 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 $i = 1, 2, \ldots, n-1$, 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 methods 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. $g_j(.)$ 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 weigths when there is uncertainity. 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

2.1. Software Architecture

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

```
abstract type MCDMResult end
```

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

```
struct TopsisResult <: MCDMResult
    decisionMatrix::DataFrame
    weights::Array{Float64,1}
    normalizedDecisionMatrix::DataFrame
    normalizedWeightedDecisionMatrix::DataFrame
    bestIndex::Int64
    scores::Array{Float64,1}
end
```

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

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

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

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

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

and

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

present two distinct ways of downloading and installing the package.

2.2. Software Functionalities

The package implements methods for TOPSIS[1] [38], ELECTRE[2][39], PROMETHEE[3] [40], DEMATEL[4] [41], MOORA[5] [42], VIKOR[6] [43, 44], AHP[7] [45], GRA[8] [46], NDS[9] [1], SAW[10] [47, 48], ARAS[11] [49], WPM[12] [48],

[1]Technique for Order Preference by Similarity to Ideal Solutions
[2]Elemination and Choice Translating Reality
[3]Preference Ranking Organization METHod for Enrichment of Evaluations
[4]The Decision Making Trial and Evaluation Laboratory
[5]Multi-Objective Optimization By Ratio Analysis
[6]VlseKriterijumska Optimizcija I Kaompromisno Resenje in Serbian
[7]Analytic Hierarchy Process
[8]Grey Relational Analysis
[9]Non-dominated Sorting
[10]Simple Additive Weighting
[11]Additive Ratio Assessment
[12]Weighted Product Model

WASPAS[13] [50], EDAS[14] [8], MARCOS[15] [5], MABAC[16] [51], MAIRCA[17] [52], COPRAS[18] [53], COCOSO[19] [54], CODAS[20] [55], CRITIC[21] [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^2s), 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:

[13] Weighted Aggregated Sum Product ASsessment
[14] Evaluation based on Distance from Average Solution
[15] Measurement Alternatives and Ranking according to COmpromise Solution
[16] Multi-Attributive Border Approximation area Comparison
[17] Multi Attributive Ideal-Real Comparative Analysis
[18] COmplex PRoportional ASsessment
[19] Combined Compromise Solution
[20] COmbinative Distance-based ASsessment
[21] CRiteria Importance Through Intercriteria Correlation

```
julia> using JMcDM, DataFrames
julia> df = DataFrame(
:age        => [6.0, 4, 12],
:size       => [140.0, 90, 140],
:price      => [150000.0, 100000, 75000],
:distance   => [950.0, 1500, 550],
:population => [1500.0, 2000, 1100]);
```

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

```
julia> w  = [0.35, 0.15, 0.25, 0.20, 0.05];
julia> fns = makeminmax([minimum, maximum, minimum, minimum, maximum]);
julia> result = topsis(df, w, fns);
julia> result.scores
3-element Array{Float64,1}:
0.5854753145549456
0.6517997936899308
0.41850223305822903

julia> result.bestIndex
2
```

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

```
julia> result = saw(df, w, fns);
julia> result.bestIndex
2
```

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

```
julia> result = wpm(df, w, fns);
julia> result.bestIndex
2
```

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

2.3.1. Game Solver

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

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

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

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

```
julia> result.value
0.0
julia> result.row_player_probabilities
3-element Array{Float64,1}:
0.3333333333333333
0.33333333333333337
0.3333333333333333
```

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

3. Illustrative Examples

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

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

```
julia> result1
3×7 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

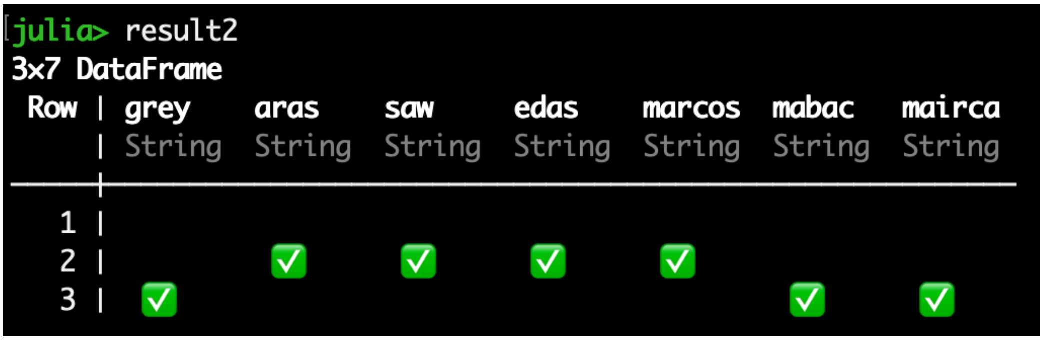
Figure 1 represents the output of the `summary()` call for methods TOPSIS, ELECTRE, VIKOR, MOORA, COCOSO, WPM, and WASPAS, respectively.

```
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 easly perform sequantial 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 String	aras String	saw String	edas String	marcos String	mabac String	mairca String
1							
2		✅	✅	✅	✅		
3	✅					✅	✅

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

potential for increasing user productivity. Seeing the different results produced by the methods together also helps to discover which parameters the research is more sensitive to and the reasons for them.

5. Conclusions

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

6. Conflict of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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