Summary

JMcDM is a Julia package that implements some leading multiple-criteria decision-making tools for both researchers and developers. By having a REPL tool, Julia is well suited for researchers to perform their analysis using different methods and comparing their results. JMcDM also provides the necessary infrastructure, utility functions, and a standardized API for implementing recently published methods. The package brings MCDM (Multiple-Criteria Decision-Making) tools to a relatively new language such as Julia with its significant performance promises. Besides Julia being a new language, the methods developed in the package are designed to be familiar to users who previously used the R and Python languages. This paper presents the basics of the design, example usage, and code snippets.

Introduction

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 the 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 the multi-dimensional case, the binary domination operator $\succ$ applied on points $a$ and $b$, $a \succ b$, is true if each item in $a$ is not worse than the corresponding item in $b$ and at least one item is better than the corresponding item in $b$ (Deb et al., 2002). On the other hand, the more relaxed operator $\succeq$ returns true if each item in $a$ is as good as the corresponding item in $b$ (Greco et al., 2016). Several outranking methods in MCDM (Multiple-Criteria Decision Making) define a unique ranking mechanism to select the best alternative among others.

Suppose a decision process has $n$ alternatives and $m$ criteria that are either to be maximized or minimized. Each single criterion has a weight $0 \leq w_i \leq 1$ where $\sum_i w_i = 1$ and is represented by a function $f_i$, which is either maximum or minimum. $g_j(.)$ is an 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 shown in Table 1 without loss of generality. When $A_1$, $A_2$, $\ldots$, $A_n$ are alternatives and $C_1$, $C_2$, $\ldots$, $C_m$ are different situations of a single criterion then the decision problem is said to be a 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 $C_j$. 

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State of the field

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, computer software is often required. While some previous applications only focused on a single method, some applications appear to include multiple methods. PyTOPS is a Python tool for TOPSIS (Yadav et al., 2019). Super Decisions is a software package that is mainly focused on AHP (Analytic Hierarchy Process) and ANP (Analytic Network Process) (Adams & Saaty, 2003). Visual Promethee implements the Promethee method on Windows platforms (Mareschal & Smet, 2009). M-BACBETH is another commercial software product that implements MACBETH with an easy to use GUI (Bana e Costa et al., 2011). 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 II and I, MAPPAC and ORESTE) (Jablonsky, 2014). The DEA Frontier 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) (Zhu, 2014).

Statement of need

While the applications mentioned above are lacking in features such as the number of methods included, being programmable, being free, and the results being comparable by the researcher, JM manufact clearly differs as it has all of these features. JM is designed to provide a developer-friendly library for solving multiple-criteria decision problems in Julia (Bezanson et al., 2017). Since Julia is a dynamic language, it is also useful for researchers who are familiar with REPL (Read-Eval-Print-Loop) environments. The package includes multi-criteria decision methods as well as a game solver for zero-sum games, and methods for single criterion methods.

The package implements methods for AHP (Saaty, 1977), ARAS (Edmundas Kazimieras Zavadskas & Turskis, 2010), COCOSO (Yazdani et al., 2019), CODAS (Keshavarz Ghorabaee et al., 2016), COPRAS (Edmundas Kazimieras Zavadskas et al., 1994), CRITIC (Diakoulaki et al., 1995), DEMATEL (Gabus & Fontela, 1972), EDAS (Ghorabaee et al., 2015), ELECTRE (Roy, 1968), Entropy (Shannon, 1948), GRA (Ju-Long, 1982), MABAC (Pamučar & Ćirović, 2015), MAIRCA (Pamučar et al., 2014), MARCOS (Stević et al., 2020), MOORA (Brauers & Zavadskas, 2006), NDS (Deb et al., 2002), PROMETHEE (Brams & Vincke, 1985), SAW (Churchman & Ackoff, 1954; Triantaphyllou & Mann, 1989), TOPSIS (Hwang & Yoon, 1981), VIKOR (Opricovic, 1998; Opricovic & Tzeng, 2002), WASPAS (E. K. Zavadskas et al., 2012), and WPM (Triantaphyllou & Mann, 1989) for multiple-criteria tools. This list of selected methods includes both classical (TOPSIS, ELECTRE, PROMETHEE, etc.) and modern (COCOSO, MABAC, MARCOS, etc.) tools of the relevant literature.

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The package also performs Data Envelopment Analysis (DEA) ([Charnes et al., 1978](#)) and includes a method for solving zero-sum games. Although these methods may seem different from the methods mentioned above, they are basically members of the same method family and solve similar problems. DEA differs from the above methods in that it is not an outranking method but compares efficiencies of decision units. Solving zero-sum games is also a multi-criteria decision-making problem, but this time, unlike outranking methods, both the rows and columns of the decision matrix show alternative strategies.

The full set of other tools and utility functions are listed and documented in the source code as well as in the online documentation.

### Installation and basic usage

**JMcDM** can be downloaded and installed using the Julia package manager by typing

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

and can be loaded before using any functions by typing

```
 julia> using JMcDM
```

in Julia REPL.

Suppose a decision problem is given in the table below.

| Criteria | Age | Size | Price | Distance | Population |
|----------|-----|------|-------|----------|------------|
| Weights  | 0.35| 0.15 | 0.25  | 0.20     | 0.05       |
| Functions| min | max  | min   | min      | max        |
| A₁       | 6   | 140  | 150000| 950      | 1500       |
| A₂       | 4   | 90   | 100000| 1500     | 2000       |
| A₃       | 12  | 140  | 75000 | 550      | 1100       |

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

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

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

```julia
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.

References

Adams, W., & Saaty, R. (2003). Super decisions software guide. In *Super Decisions* (Vol. 9, p. 43). [https://superdecisions.com/sd_resources/v28_man01.pdf](https://superdecisions.com/sd_resources/v28_man01.pdf)

Bana e Costa, C. A., Corte, J.-M. de, & Vansnick, J.-C. (2011). *MACBETH (measuring attractiveness by a categorical based evaluation technique)*. John Wiley & Sons, Inc. [https://doi.org/10.1002/9780470400531.eorms0970](https://doi.org/10.1002/9780470400531.eorms0970)

Bezanson, J., Edelman, A., Karpinski, S., & Shah, V. B. (2017). Julia: A fresh approach to numerical computing. *SIAM Review*, 59(1), 65–98. [https://doi.org/10.1137/141000671](https://doi.org/10.1137/141000671)

Brans, J.-P., & Vincke, P. (1985). Note—a preference ranking organisation method: (the PROMETHEE method for multiple criteria decision-making). In *Management science* (No. 6; Vol. 31, pp. 647–656). INFORMS. [https://doi.org/10.1287/mnsc.31.6.647](https://doi.org/10.1287/mnsc.31.6.647)

Brauers, W. K., & Zavadskas, E. K. (2006). The MOORA method and its application to privatization in a transition economy. In *Control and cybernetics* (Vol. 35, pp. 445–469).

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444. [https://doi.org/10.1016/0377-2217(78)90138-8](https://doi.org/10.1016/0377-2217(78)90138-8)

Churchman, C. W., & Ackoff, R. L. (1954). An approximate measure of value. *Journal of the Operations Research Society of America*, 2(2), 172–187. [https://doi.org/10.1287/opre.2.2.172](https://doi.org/10.1287/opre.2.2.172)

Satman et al., (2021). JMcDM: A Julia package for multiple-criteria decision-making tools. *Journal of Open Source Software*, 6(65), 3430. [https://doi.org/10.21105/joss.03430](https://doi.org/10.21105/joss.03430)
Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation, 6*(2), 182–197. https://doi.org/10.1109/4235.996017

Diakoulaki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The critic method. *Computers & Operations Research, 22*(7), 763–770. https://doi.org/10.1016/0305-0548(94)00059-h

Gabus, A., & Fontela, E. (1972). World problems, an invitation to further thought within the framework of DEMATEL. In *Battelle Geneva Research Center, Geneva, Switzerland* (pp. 1–8).

Ghorabaee, M. K., Zavadskas, E. K., Olfat, L., & Turskis, Z. (2015). Multi-criteria inventory classification using a new method of evaluation based on average solution (EDAS). *Informatica, 26*(3), 435–451. https://doi.org/10.15388/informatica.2015.57

Greco, S., Figueira, J., & Ehrgott, M. (2016). *Multiple criteria decision analysis* (Vol. 37). Springer. https://doi.org/10.1007/978-1-4939-3094-4

Hwang, C.-L., & Yoon, K. (1981). *Methods for multiple attribute decision making*. In *Multiple attribute decision making* (pp. 58–191). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-48318-9_3

Jablonsky, J. (2014). MS Excel based software support tools for decision problems with multiple criteria. *Procedia Economics and Finance, 12*, 251–258. https://doi.org/10.1016/s2212-5671(14)00342-6

Ju-Long, D. (1982). Control problems of grey systems. *Systems & Control Letters, 1*(5), 288–294. https://doi.org/10.1016/s0167-6911(82)80025-x

Keshavarz Ghorabaee, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2016). A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. In *Economic Computation and Economic Cybernetics Studies and Research* (No. 3; Vol. 50, pp. 25–44). Academy of Economic Studies in Bucharest. http://www.ecocyb.ase.ro/nr20163/02

Mareschal, B., & Smet, Y. D. (2009, December). Visual PROMETHEE: Developments of the PROMETHEE - GAIA multicriteria decision aid methods. 2009 IEEE International Conference on Industrial Engineering and Engineering Management. https://doi.org/10.1109/ieem.2009.5373124

Opricovic, S. (1998). Multicriteria optimization of civil engineering systems. In *Faculty of Civil Engineering, Belgrade* (No. 1; Vol. 2, pp. 5–21).

Opricovic, S., & Tzeng, G.-H. (2002). Multicriteria planning of post-earthquake sustainable reconstruction. *Computer-Aided Civil and Infrastructure Engineering, 17*(3), 211–220. https://doi.org/10.1111/1467-8667.00269

Pamučar, D., & Ćirović, G. (2015). The selection of transport and handling resources in logistics centers using multi-attributive border approximation area comparison (MABAC). *Expert Systems with Applications, 42*(6), 3016–3028. https://doi.org/10.1016/j.eswa.2014.11.057

Pamučar, D., Vasin, L., & Lukovac, L. (2014). Selection of railway level crossings for investing in security equipment using hybrid TEL-MARICA model. *XVI International Scientific-Expert Conference on Railway, Railcon, 89–92*. https://doi.org/10.13140/2.1.2707.6807

Roy, B. (1968). Classement et choix en présence de points de vue multiples. *RAIRO - Operations Research - Recherche Opérationnelle, 2*(V1), 57–75. https://doi.org/10.1051/ro/196802v100571

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*(3), 234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Satman et al., (2021). *JMcdM: A Julia package for multiple-criteria decision-making tools*. *Journal of Open Source Software, 6*(65), 3430. 5 https://doi.org/10.21105/joss.03430
Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27(3), 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Stević, Željko, Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers & Industrial Engineering*, 140, 106231. https://doi.org/10.1016/j.cie.2019.106231

Triantaphyllou, E., & Mann, S. H. (1989). An examination of the effectiveness of multidimensional decision-making methods: A decision-making paradox. *Decision Support Systems*, 5(3), 303–312. https://doi.org/10.1016/0167-9236(89)90037-7

Yadav, V., Karmakar, S., Kalbar, P. P., & Dikshit, A. K. (2019). PyTOPS: A Python based tool for TOPSIS. *SoftwareX*, 9, 217–222. https://doi.org/10.1016/j.softx.2019.02.004

Yazdani, M., Zarate, P., Zavadskas, E. K., & Turskis, Z. (2019). A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. *Management Decision*, 57(9), 2501–2519. https://doi.org/10.1108/md-05-2017-0458

Zavadskas, Edmundas Kazimieras, Kaklauskas, A., & Sarka, V. (1994). The new method of multicriteria complex proportional assessment of projects. In *Technological and economic development of economy* (No. 3; Vol. 1, pp. 131–139).

Zavadskas, Edmundas Kazimieras, & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multicriteria decision-making. In *Technological and Economic Development of Economy* (No. 2; Vol. 16, pp. 159–172). Taylor & Francis. https://doi.org/10.3846/tede.2010.10

Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2012). Optimization of weighted aggregated sum product assessment. *Electronics and Electrical Engineering*, 122(6). https://doi.org/10.5755/j01.eee.122.6.1810

Zhu, J. (2014). *Quantitative models for performance evaluation and benchmarking*. Springer International Publishing. https://doi.org/10.1007/978-3-319-06647-9

Satman et al., (2021). JMicDM: A Julia package for multiple-criteria decision-making tools. *Journal of Open Source Software*, 6(65), 3430. https://doi.org/10.21105/joss.03430