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A systematic review of multi-criteria decision-making applications in reverse logistics

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Abstract

Multi-criteria decision-making (MCDM) methods have been applied to various reverse logistics problems. In order to develop a reliable knowledge base through accumulating knowledge from previous studies, we conduct a systematic review of the applications of different MCDM methods to different reverse logistics problems. We found 80 relevant papers published in scientist journals, which are application of different MCDM methods to different reverse logistics problems. We classify the literature based on two dimensions problem context and methodology. The results show that recycling and AHP are the most researched problem and methodology respectively. We finally suggest some future research directions with respect to problem context and methodology.

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Keywords: reverse logistics; multi-criteria decision-making; systematic review

1. Introduction

According to The Council of Supply Chain Management Professionals (CSCMP) “Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements”. Although this definition contains both forward and reverse flows, when we are using ‘logistics’ we usually refer to the forward flow, while for reverse flow we use ‘reverse logistics’.

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Drawing on the CSCMP definition we can define reverse logistics as "planning, implementing, and controlling the efficient and effective flow and storage of goods, services and related information between the point of consumption and the point of origin for economical or environmental purposes". It is important to note that although reverse logistics (RL) can greatly address some environmental concerns in logistics and supply chain management, it is different than 'green logistics' (GL). That is, although there are some activities to which we can apply both RL and GL, there are some activities which are unique to either reverse logistics or green logistics. Adopting from Rogers and Tibben-Lembke (2001), here we classify these activities to three classes:

- Only applied to GL: 'packaging reduction', 'air emission', 'noise emission', 'environmental impact of mode selection';
- Only applied to RL: 'product return', 'marketing return', 'secondary markets';
- Applied to both GL and RL: 'recycling', 'remanufacturing', 'reusable packaging', 'waste management', 'disassembly', 'design'.

So we consider the last two classes to draw the boundary of this paper.

In the context of RL there are different decision-makers such as governmental bodies, buying companies and suppliers that are responsible for several decisions. One approach to formulate complex decisions is multi-criteria decision-making where a (or a group of) decision-maker(s) should evaluate a number of alternatives with respect to a set of decision criteria in order to select the (or a number of) best alternative(s). The methods which are used for this kind of decision-making problems called multi-criteria decision-making (MCDM) methods. MCDM methods have been widely applied to many different areas. Here we refer to some of the review papers: in sustainable energy planning (Pohekar and Ramachandran 2004), in supplier evaluation and selection (Ho, Xu et al. 2010), in financial decision-making (Zopounidis and Doumpos 2002), in natural resource management (Mendoza and Martins 2006), and in construction (Jato-Espino, Castillo-Lopez et al. 2014). We did not find any review paper in the field of RL, however, we found two review papers which are close to one activity in RL: waste management (Achillas, Moussiopoulos et al. 2013, Soltani, Hewage et al. 2015). In this paper we conduct a systematic review of the applications of MCDM methods in the field of RL.

In the next section, the research methodology used for the systematic review is described. Section 3 reports the analysis and synthesis. The conclusion and future research directions are discussed in Section 4.

2. Research methodology

In this section, we describe the research methodology, a systematic review, we used in this paper. A systematic review is defined as "a specific methodology that locates existing studies, selects and evaluates contributions, analyses and synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known" (Denyer 2009). In this paper we follow the five-step procedure proposed by (Denyer 2009) as follows.

Step 1. Question formulation: in this step, clear questions should be made to establish the focus of the study, and to frame the inclusion criteria. To formulate the questions we follow the CIMO-Logic proposed by (Denyer, Tranfield et al. 2008). CIMO is the acronym for Context, Intervention, Mechanisms, and Outcome. This logic is constructed as follows: "in this class of problematic Contexts, use this Intervention type to invoke these generative Mechanism(s), to deliver these Outcome(s)" (Denyer, Tranfield et al. 2008). Applying this logic to this study, we formulate the design proposition to identify the four main elements:

"*If a firm aims to make a decision about a reverse logistics problem characterized by multiple criteria and multiple alternatives (C), it should evaluate the alternatives using a multi-criteria decision-making method (I) based on one or more decision-makers (experts) opinion to identify the importance of different alternatives (M) in order to select the best one (O)*".

Step 2. Locating studies: in this step, we should locate, select and appraise the relevant studies as much as possible. To this end, we searched the literature via the scientific search engines Scopus and Web of Knowledge in a structured way. That is to say, we used 27 keywords and acronyms. We used search strings, simple operators, and Boolean logic to group the keywords to make the search more efficient. More specifically, we conducted the search using the following formulation: (redistribut* OR refurbish* OR "green supply chain" OR "closed loop supply chain" OR "end-of-life products" OR "product recovery" OR "product returns" OR "reverse logistics" OR recycling OR remanufactur*) AND (MCDM OR MCDA OR "multi* criteria" OR MADM OR AHP OR ANP OR TOPSIS OR ELECTRE OR PROMETHEE OR VIKOR OR DEMATEL OR MACBETH OR MAUT OR MODM OR MOOP OR "multi* objective*").The searches were conducted on 20 January 2015.

Step 3. Study selection and evaluation: in this step, a number of inclusion and exclusion criteria are defined in order to focus on relevant and important papers. To this end, we searched the literature via the scientific search engines Scopus and Web of Science in a structured way. For the sake of quality, we only included peer-reviewed English papers (including review papers, and articles in press). The initial search resulted in 453 papers. To ensure the relevance of the papers, we read the abstract of all papers. Excluding irrelevant and non-English papers we ended up with 312 papers in total. There were several fully irrelevant papers which appeared in our initial search. For instance, we found many papers in biology and medicine where ANP or AHP stand for something other than 'analytic hierarchy process' or 'analytic network process'. Due to the large number of papers we classified the papers to two categories: multi-criteria decision-making (MCDM), and multi-objective decision-making (MODM). We found 152 papers in MCDM and 156 papers in MODM, and 4 generic papers. In this paper we focus on the first category, and we review the second category in another paper. Reading all the 152 papers we found 80 relevant. That is, we further excluded works solely devoted to green supply chain management or GL, or papers solely focused on methodology.

Step 4. Analysis and synthesis: in this step, the relevant information is extracted from the collection of 80 most relevant papers. To extract unified information we used the designed questions in Step 1. The results of this step are description of the works, making association between the works, and classifying them which are comprehensively presented in the next section.

Step 5. Reporting and using the results: according to this step the results of the systematic review should be reported as an empirical report including an introduction, methodology, findings and results, and conclusion.

The first three steps have been sufficiently discussed above. We now focus of the last two steps of the methodology (analysis and synthesis, and reporting and using the results) in the next section (analyzing and reporting).

3. Analyzing and reporting

Fig. 1 and Fig. 2 respectively show the growth of the number of papers published in the last 25 years, and the journals published these papers.

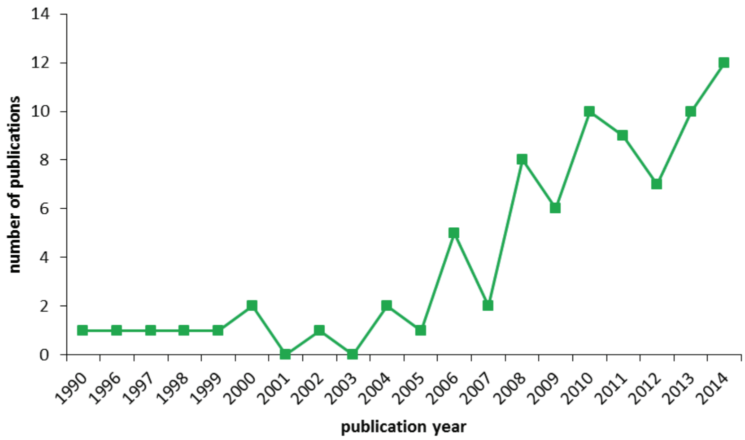

Fig. 1. Number of publications during the last 25 years

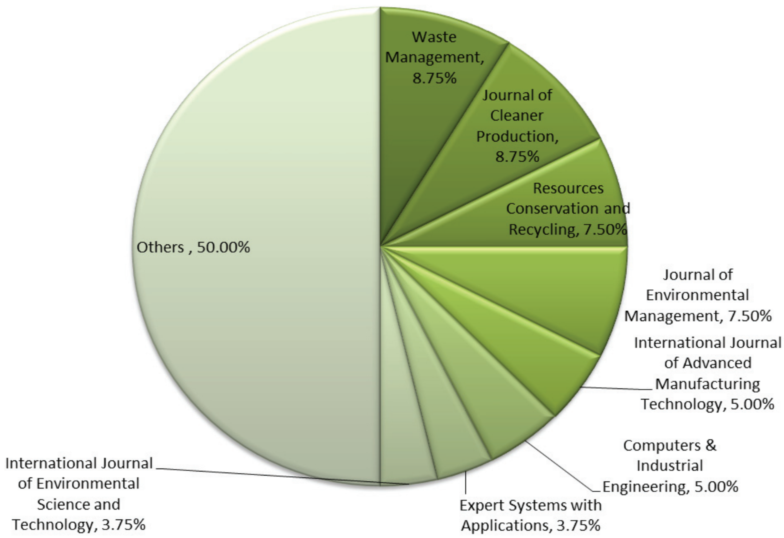

Fig. 2. The publication journals

As can be seen there has been an increasing trend in the number of applications of MCDM methods in RL. The leading journals in this area are *Waste Management, Journal of Cleaner Production, Resources Conservation and Recycling, and Journal of Environmental Management*. The share of these and also the other journals can be found in Fig. 2.

The literature might be classified in different ways. We classify the literature based on two dimensions: content, methodology. Table 1 shows the classification considering these two dimensions. We will discuss these two dimensions in the next sections.

Table 1 Problem/methodology classification of the papers

	Recycling	Remanufacturing/ Reuse	Disassembly/ Design	Waste management	General
(fuzzy) AHP	(Kim, Choi et al. 2013); (Kim, Jang et al. 2013); (Ghorbannezhad, Azizi et al. 2013); (Contreras, Hanaki et al. 2013); (Kaya 2012); (Knoeri, Binder et al. 2011); (Hsu and Liu 2011); (Lin, Wen et al. 2010); (Hsu, Lee et al. 2010); (Kim, Hwang et al. 2009); (Madu, Kuei et al. 2002); (Yu, Jin et al. 2000)	*Remanufacturing*: (Tian, Chu et al. 2014); (Subramoniam, Huisingh et al. 2013); (Du, Cao et al. 2012); (Jiang, Zhang et al. 2011); (Hambali, Sapuan et al. 2010) *Reuse:* (Zhou, Huang et al. 2012)	(Cao, Chen et al. 2014); (Hambali, Sapuan et al. 2009); (Wu, Lo et al. 2008); (Kuo, Chang et al. 2006)	(Karimi, Mehrdadi et al. 2011); (Karagiannidis, Papageorgiou et al. 2010) (Alidi 1996); (Brent, Rogers et al. 2007); (Karamouz, Zahraie et al. 2007)	(Subramanian, Gunasekaran et al. 2014); (Shaik and Abdul-Kader 2013); (Barker and Zabinsky 2011); (Efendigil, Onut et al. 2008); (Cram, Sommer et al. 2006)
ANP	(Shiue and Lin 2012)		(Gungor 2006)	(Bottero, Comino et al. 2011)	(Cheng and Lee 2010); (Ravi, Shankar et al. 2008); (Ravi, Shankar et al. 2005)
ELECTRE	(Hatami-Marbini, Tavana et al. 2013); (Achillas, Vlachokostas et al. 2010)			(El Hanandeh and El-Zein 2010); (Bellehumeur, Vasseur et al. 1997); (Banias, Achillas et al. 2010)	

PROMETHEE	(Chen, Ngo et al. 2012); (Rousis, Moustakas et al. 2008); (Queiruga, Walther et al. 2008); (Walther, Spengler et al. 2008)	(Khelifi, Dalla Giovanna et al. 2006)	(Ghazilla, Taha et al. 2014)	(Carroll, Goonetilleke et al. 2004); (Khalil, Goonetilleke et al. 2004); (Al-Rashdan, Al-Kloub et al. 1999); (Margeta, Fontane et al. 1990); (Geldermann, Spengler et al. 2000); (Spengler, Geldermann et al. 1998)	
TOPSIS/VIKOR /AHP and TOPSIS	(Vinodh, Prasanna et al. 2014)	(Wadhwa, Madaan et al. 2009)	(Avikal, Jain et al. 2014); (Huang, Zhang et al. 2011)	(Su, Hung et al. 2010)	(Senthil, Srirangacharyulu et al. 2014); (Kannan, Pokharel et al. 2009) (Rao 2008); (Rao 2009)
Others/ hybrid	(Dhouib 2014); (Stefanopoulos, Yang et al. 2014); (Chen, Ngo et al. 2013); (Hsu, Wang et al. 2012); (Kara 2011); (Park, Tahara et al. 2006); (Rahman and Subramanian 2012)	*Remanufacturing:* (Zhu, Sarkis et al. 2014) *Reuse:* (Almeida, Vieira et al. 2013); (Kaklauskas, Rute et al. 2011)		(Aragonés-Beltrán et al. 2009); (Hanan et al. 2013)	(Kannan, Diabat et al. 2014); (Gamberini, Gebennini et al. 2010); (Tuzkaya and Gulsun 2008); (Shaik and Abdul-Kader 2014)

3.1. Problem context-based classification

Recycling: Recycling is defined as "the process of systematically collecting, sorting, decontaminating and returning of waste materials to commerce as commodities for use or exchange (Wiard and Sopko, 1989, p. 3 cited in Pohlen and Theodore Farris (1992)). As can be seen from Table 1, recycling is the most-researched problem in literature. That is, 27 studies out of 80 have investigated recycling problem. Most of these studies are about finding the best recycling technology/strategy. For instance, Contreras, Hanaki et al. (2013) have used AHP for choosing the best management alternative for recycling of anthropogenic nutrients from wastewater. Several studies have used MCDM methods to find the best recycling scenario for WEEE (Kaya 2012, Kim, Jang et al. 2013, Yu, Jin et al. 2000, Rousis, Moustakas et al. 2008, Achillas, Vlachokostas et al. 2010).

Remanufacturing and Reuse: "Remanufacturing is the transformation of used units, consisting of components and parts, into units which satisfy exactly the same quality and other standards as new units" (Jayaraman, Guide Jr et al. 1999). "Reuse is the process of collecting used materials, products, or components from the field, and distributing or selling them as used" (Beamon 1999). No additional processing is done on the used products, materials or components. In this category we have some studies which have applied MCDM to find the best remanufacturing technology (Wadhwa, Madaan et al. 2009, Jiang, Zhang et al. 2011), while others have investigated the importance of factors (Subramoniam, Huisingh et al. 2013, Tian, Chu et al. 2014) or barriers (Zhu, Sarkis et al. 2014) affecting remanufacturing processes. Assessing the re-manufacturability or re-usability, and proper material selection for the purpose of re-manufacturability or re-usability are the topics of other studies in this category.

Disassembly and Design: "Disassembly is the process of systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of the parts due to the process" (Brennan, Gupta et al. 1994). Design is also a very important activity which can be considered in order to maximize the reusability and/or recyclability of the materials, components, and products. Some researchers have applied MCDM methods to find the best design for the products in order to maximize their recyclability, re-manufacturability or re-usability (reuse-oriented design) (Gungor 2006, Kuo, Chang et al. 2006, Wu, Lo et al. 2008, Hambali, Sapuan et al. 2009, Cao, Chen et al. 2014, Ghazilla, Taha et al. 2014). Others have investigated problems like prioritizing the assignment of tasks to the disassembly workstations (Avikal, Jain et al. 2014) or material selection (Huang, Zhang et al. 2011).

Waste management: "Waste management is defined by all the activities including collection, transport, handling, treatment, material and energy recovery and disposal of waste" (Gentil, Damgaard et al. 2010). Waste management is a very broad topic. In this paper we include the following topics: management of wastewater, WEEE, Construction & Demolition, industrial waste, hazardous, hospital, and used oil, and do not include management of 'municipal solid waste' and 'nuclear/radioactive waste'. For a review of MCDM methods in waste management including the last two sub-topics we refer to Achillas, Moussiopoulos et al. (2013) and Soltani, Hewage et al. (2015).Table 1 shows that this is also a very important category. Most studies of this category are about finding the best waste management strategy. A few studies have used MCDM methods to find the site selection for waste management (Carroll, Goonetilleke et al. 2004, Khalil, Goonetilleke et al. 2004).

General: Under this category we consider problems which are related to more than one problem in RL, or problems which cannot be categorized into the aforementioned categories. Several different and interesting problems are investigated in this category. From ranking the motivating factors of end-of-life (EOL) tire management in India (Kannan, Diabat et al. 2014), to finding the best transportation network for WEEE (Gamberini, Gebennini et al. 2010), to finding the best centralized return center in a reverse logistics network (Tuzkaya and Gulsun 2008). RL performance measurement is the topic of two papers (Shaik and Abdul-Kader 2014) (Shaik and Abdul-Kader 2013). Another interesting problem of this category which has been investigated by several researchers is third party logistics provider selection for RL (Kannan, Pokharel et al. 2009, Senthil, Srirangacharyulu et al. 2014, Cheng and Lee 2010, Efendigil, Onut et al. 2008).

3.2. Methodology-based classification

AHP/ANP: Analytic hierarchy process (AHP) is a pairwise comparison-based method proposed by (Saaty 1977). An MCDM problem is first formulated as a hierarchy including several levels. The first level represents the goal, the second level shows the main decision criteria, the next levels show the sub-criteria, and the last level indicate the alternatives. The elements of each level are compared in a pairwise fashion forming a pairwise comparison matrix. Different methods (the principal eigenvector technique (Saaty 1977), the weighted least square method (WLSM) (Chu, Kalaba et al. 1979), the logarithmic least square method (LLSM) or geometric mean method (GMM) (Crawford and Williams 1985), goal programming method (GPM) (Bryson 1995, Lin 2005)) are used to calculate the weights. The relative weights found from each level are aggregated to identify the best alternative. Analytic network process (ANP) is another MCDM method proposed by Saaty (1996) to address the interdependency and feedback problems between the criteria, the problems that, if exist, cannot be handled by AHP. While in the conventional AHP and ANP a 1-9 scale is used to compare the criteria/alternatives, fuzzy AHP and Fuzzy ANP use linguistic variables (e.g., much more important), and their corresponding fuzzy numbers to compare the criteria/alternatives. There are many variants of fuzzy AHP and fuzzy ANP, here, we refer to some: fuzzy AHP (Van Laarhoven and Pedrycz 1983, Chang 1996, Mikhailov 2000, Csutora and Buckley 2001) and fuzzy ANP(Mikhailov and Singh Madan 2003) among others.

This category, by far, has the most number of applications in this field. That is from total number of applications (80) 32 papers have applied AHP or fuzzy AHP, and six papers have used ANP, together about 48% of the papers we reviewed.

ELECTRE: ELECTRE (ELimination Et Choix Traduisant la REalité) (ELimination and Choice Expressing REality) we originally proposed by Ror (1968), as an MCDM to find a kernel solution based on two indices called the concordance index and the discordance index, which show the goodness of two alternatives over each other. The relation between the indices determines which alternative outranks the other one. This original model which is also called ELECTRE I cannot be used for ranking the alternatives. It is rather used to derive the kernel set. Other variants of ELECTRE have been used to enrich the original model. For instance, ELECTRE II (Roy and Bertier 1971) was proposed to address the inefficiency of ELECTRE I in ranking. ELECTRE III (Roy 1978) extends the crisp outranking relations to fuzzy outranking relations, and ELECTRE IV (Roy and Hugonnard 1982) is an attempt to simplify ELECTRE III. To have more information about different versions of ELECTRE we refer to (Figueira, Mousseau et al. 2005).

This category has, in total, five applications, two papers in recycling and three papers in waste management, making it as the category with the lowest number of applications in this field.

PROMETHEE: PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) was developed by (Brans and Vincke 1985, Brans, Vincke et al. 1986). It is a pairwise comparison-based outranking method which is used to solve MCDM problems. Different preference functions are used to convert the pairwise comparisons to uni-criterion preference degree. A multi-criteria preference degree is then calculated to compare the criteria to each other. Then we calculate leaving flow and entering flow, the difference of which being the net value that is the basis for determining the outranking of the alternatives by each other. To find different versions of PROMETHEE we refer to Brans and Mareschal (2005).

This category has the second rank (after AHP, and if we do not count the other/hybrid methodologies –which is fair), with the total number of 12 papers. It is interesting that most of the application of this method belong to the waste management category.

TOPSIS/VIKOR/(fuzzy)AHP and TOPSIS: TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) was proposed by Hwang (1981) and later extended by Hwang, Lai et al. (1993) and Lai, Liu et al. (1994). According to the conventional TOPSIS, the best alternative is the one which has "the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS)" (Lai, Liu et al. 1994). The performance rating used in TOPSIS which shows the performance of each alternative with respect to different criteria usually involves uncertainty, which has called for fuzzy TOPSIS. Here we refer to some fuzzy TOPSIS methods: (Wang and Elhag 2006, Chen and Tsao 2008). VIKOR (VlseKriterijumska Optimizacija I Kompromisno) was developed by (Opricovic 1998) another MCDM method is similar to TOPSIS in that it also ranks and selects the best alternative from a set of alternatives based on closeness to ideal solution. VIKOR addresses the inefficiency of TOPSIS in inability of ranking the alternatives. We refer to the comparison study (Opricovic and Tzeng 2004) for more information. Combination of (fuzzy) AHP and (fuzzy) TOPSIS has also become a popular MCDM combination in which, usually, (fuzzy) AHP is used to find the criteria weights, and (fuzzy) TOPSIS is used to rank the alternatives.

Here we have nine papers, most of which belong to general applications. We think that because for the general applications, usually more than one problem in investigated a hybrid methodology like AHP-TOPSIS is more desirable.

Other/Hybrid methodologies: In this category we have the applications in which more than one MCDM is used. We also, here, report other methodologies which are used in the literature: DEMATEL (Decision Making Trial and Evaluation Laboratory) initially proposed by Fontela (1974) is a simple pairwise comparison-based method which illustrates the interrelations among the criteria. In most applications, DEMATEL is used with other MCDM methods. SAW (simple additive weighting) method initially applied by (Churchman and Ackoff 1954) is perhaps the most known MCDM method which, to find the overall value of each alternative, uses a simple equation that is a multiproduct of the criteria weights by the alternative utilities with respect to the criteria. MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) (Bana e Costa and Vansnick 1994) is a simple MCDM method, which uses qualitative comparisons to compare the alternatives with respect to their attractiveness for different criteria.

For 16 application (out of 80) we have hybrid methodologies like DEMATEL-ANP-VIKOR (Hsu, Wang et al. 2012), or less commonly used MCDM methods like interpretive structural modeling (ISM) (Kannan, Diabat et al. 2014).

4. Conclusion and future directions

We systematically reviewed the literature of applications of MCDM methods in reverse logistics (RL). In total, 80 papers have been found relevant. We classified the literature based on problem, and also based on methodology. With respect to problem, recycling is the most-researched problem followed by waste management, general, remanufacturing, reuse, design, and disassembly. With respect to methodology, AHP and PROMETHEE are among the most commonly used methodologies in this field. Several interesting insights have been found from these applications. Generally speaking the number of applications of MCDM in the field of RL is very limited. As the problems in this field are inherently very complex, and with multiple criteria, we think this field needs a greater deal of attention. From this classification of the literature we can see that some RL problems have not been adequately investigated, like reuse. We think this is a very important category for which we found just a few applications of MCDM. We also found that when a real-world problem is investigated (and the model is not applied simply to a numerical example) a single method is used, and not a hybrid method. We think this is also very important insight. Although most MCDM methods are relatively simple and understandable by decision-makers, hybrid methods are more sophisticated hence less understandable. There are some other robust MCDM methods, which have not been used in this field and we suggest using them.

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