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Combining Analytic Hierarchy Process (AHP) with role-playing games for stakeholder engagement in complex transport decisions

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Abstract

This paper presents a procedure for the structuring of a transport decision-making problem and evaluation of the solutions proposed from a multi-stakeholder multi-criteria perspective. Analytic Hierarchy Process (AHP) is used as multicriteria decision technique, while a role-playing game is used to reproduce a participatory process where University students act as key stakeholders. The case study regards the building of a new metro station in Catania (Italy), which will be the nearest station to a big University district. A dedicated transit system linking the metro station and the district is under study and four different alternatives have been proposed. Students were initially informed about the objectives of key stakeholders in order to be able to play the different roles. A hierarchy of the problem was built with them and AHP was used to elicit their preferences and evaluate priorities for each stakeholder group. A comparison between a mathematical aggregation of individual priorities and a consensus vote was performed to verify the differences between the two different methods and their compliance with the stated stakeholder preferences. AHP-based participatory procedure proved to be suitable to tackle the complexity of transport decisions.

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Keywords: multicriteria decision-making; stakeholder involvement; participatory process; transport planning

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1. Introduction

Transport systems are complex socio-technical systems that affect the social, economic and environmental dimensions of a territorial community with several impacts and feedbacks not easy to be foreseen (Cascetta et al., 2015). Further complexity is added by the procedural issues related to construction and operation of the transport systems and mostly for the several actors that interact in different contexts and show different interests. Transport planning is typically a decision-making process based on rationality, aimed at defining and implementing transport system operations (Ortúzar and Willumsen, 2011). It effectively means achieving aims and objectives as a result of a technical and political process, through a set of decisions that will inevitably favor some interests and expectations at the expense of others. In fact, even if a transport plan is meant to increase the net welfare of a community, the benefits will never be equally distributed among its different actors and groups interested in influencing the planning process (De Luca, 2000). Public participation in transport planning is therefore emerging as a basic component to which human and financial resources have to be dedicated from the beginning of the planning process (Cascetta and Pagliara, 2013). The word "public" is usually referred to all those potentially affected by or interested in a decision, i.e. the potential "stakeholders". Stakeholders in the transport sector can belong to different categories, i.e. institutions/authorities, transport users, transport operators, business and unions, local communities, media and financial institutions (Cascetta and Pagliara, 2013) with different levels of competences and interests (Le Pira et al., 2016a). Stakeholder engagement is therefore a necessary prerequisite for the success of a transport decision-making process. Nevertheless, a successful and effective participation process requires the use of appropriate decision-support methods and procedures. In this respect, the use of Public Participation GIS (PPGIS) should be promoted since it allows a simple visualization of the impacts of the solutions proposed (see e.g. Smith, 2002; Tang and Waters, 2005). Ex-ante behavioral analysis is also important to produce insights into stakeholders' behavior and preferences for future scenarios. In this respect, stated preference surveys are well suited to investigate stakeholders' preferences in order to forecast their individual choice behavior related to policy-making (e.g. Gatta and Marcucci, 2016). Since a collective choice is the goal of participation, it can be useful to analyze interaction processes among stakeholders aimed at consensus building. Agent-based simulations provide a useful tool to study communities of autonomous and intelligent agents, such as stakeholders linked in social networks, trying to understand the role of interaction in finding a shared decision (Le Pira et al., 2016a; 2017a; Marcucci et al., 2017). Besides, complex transport decisions requiring the evaluation of multiple and heterogeneous aspects (e.g. environmental, social, economic) need to be tackled with a multicriteria approach. Multi-Criteria Decision Making/Aiding (MCDM/A) methods are widely used in transport planning to include in a comparative assessment of alternative projects their contributions to different evaluation criteria (Figuera et al., 2005). Though stakeholders can be involved both to select the criteria and assign weights, the "rational" approach where transport planning choices are made by analysts is not always sufficient to assure that the final choice will be supported. It is necessary to involve them all along the decision-making process with the support of adequate MCDM/A methods. In this respect, the Multi-Actor Multi Criteria Analysis (MAMCA) (Macharis, 2004) is widely used in transport decision-making to gain insights in stakeholders' objectives and evaluate how the alternatives contribute to these objectives with the possibility of adapting them. There are some useful online tools/software developed to support multi-actor multi-criteria processes (e.g. Stirling and Coburn, 2014; Keseru et al., 2016). Another important aspect to consider is stakeholder interaction that can lead to opinion change and is fundamental to reach shared decisions (Le Pira et al., 2015, Le Pira et al., 2017b). Therefore, an effective participation process should be structured so to foresee the use of MCDM/A and the involvement of different stakeholders in several phases.

Based on this premise, this paper presents a procedure for the structuring of a transport decision-making problem and evaluation of the solutions proposed from a multi-stakeholder multi-criteria perspective. Analytic Hierarchy Process (AHP) is used as MCDM technique, while a role-playing game is used to reproduce a participatory process where University students act as key stakeholders. This represents the second step of a wider procedure to support a stakeholder-driven transport decision, as it will be better clarified in the next section.

The remainder of the paper is organized as follows. Section 2 is a short introduction to the methodology, with a description of the participatory procedure adopted and of the well-known AHP method. Section 3 presents the case study with a description of the decision-making context and the participation experiment. Section 4 shows the results obtained with AHP and from a comparison between the collective result obtained by mathematical aggregation and by a consensus vote. Section 5 concludes the paper by summarizing the main findings and directions for further development of the research.

2. Methodology

The overall participatory procedure consists of three steps and is summarized in Fig. 1. The case study regards the decision about a new hectometric (i.e. short-range) transit system in Catania (Italy), which should connect a new metro station with a University district. In the first step, key stakeholders have been identified and involved via in-depth interviews. A questionnaire, a GIS map and a SWOT-like graph have been used to present them the decision problem and capture their preferences and opinions. From the results of the interviews, a first hierarchy of the problem has been built (Ignaccolo et al., 2017). The second step is described in this paper. A role-playing game is used to reproduce a participatory process where University students are asked to act as key stakeholders and to obtain a ranking of transport alternatives. In the third step, a public consultation will be performed via a stated preference survey, to collect their preferences for transport system alternative configurations. In the following section, the basic elements of AHP are described together with its potential to support participatory decision-making process.

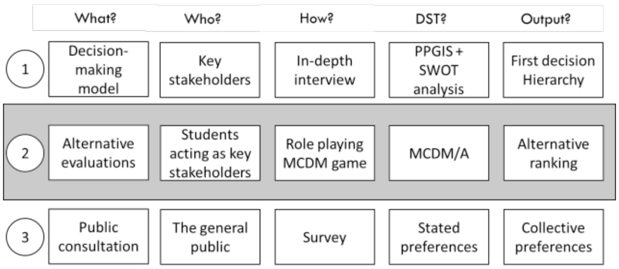

Fig. 1 The overall participatory procedure (own setup).

2.1. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a well-known MCDM/A method, developed by Thomas Saaty in the late 1970s (Saaty, 1980). It is particularly useful when decision-makers are unable to construct utility functions, differently from other methods, i.e. those based on Multi Attribute Utility Theory (MAUT) (Ishizaka and Nemery, 2013). Besides, it is easily extendable to group decision-making and, thus, it is useful to support stakeholder engagement in decision-making processes (Le Pira et al., 2015, Le Pira et al., 2017b). It allows to analyze the problem by decomposing it into decision-making hierarchy, including at least three levels, i.e. main objective (or goal), criteria and alternatives. The structure of the problem can be achieved via brainstorming sessions with experts, analyzing studies of similar problems or organizing focus groups (Ishizaka and Nemery, 2013). The elements of each level are compared between each other through pairwise comparisons, based on the importance or contribution of each of them to the element of the upper level to which they are linked. In this way, pairwise matrixes are built for each level. The pairwise comparisons are made expressing a judgment on a qualitative scale that is turned into a quantitative one, from 1 (i.e. equal importance attributed to the two elements) to 9 (i.e. extreme importance attributed to the firs element)[†] (Saaty, 1980). Then, priority scales and weights are derived from pairwise matrixes for each level by using one of the aggregation methods proposed (Saaty and Hu, 1998) and the overall priorities associated with alternatives are evaluated. Individual judgments arising from pairwise comparisons cannot be perfectly consistent, so it is necessary to perform a consistency check. The inconsistency can be measured (and, therefore, monitored) through the comparison between a consistency index derived by the matrix elements with the one obtained by purely random judgments (Saaty, 1980). In general, an inconsistency of less than 10% is accepted. AHP has been widely used to support decision-making in transport planning and management (Piantanakulchai and

[†] Reciprocal values are used when the second element is preferred to the first one (e.g. 1/9).

Saengkhao, 2003; Sivilevičius and Maskeliūnaite, 2010; Mahmoud and Hine, 2013) and in environmental planning (García-Melón et al., 2012; Romero-Gelvez and García-Melón, 2016).

When a group decision is needed, i.e. more than one decision-maker is involved in the decision, it is necessary to define an appropriate procedure to combine multiple preferences into a consensus rating. It can be derived in four ways (Ishizaka and Nemery, 2013), according to the level of aggregation (from judgments or from priorities) and the type of aggregation (mathematical or based on consensus vote). In general, a consensus vote is used when stakeholders are able to agree on the values of the matrices or on the priority vectors; vice versa, mathematical aggregation is adopted. While mathematical aggregation implies transparency and clarity of results, it might not reflect the individual preferences. On the contrary, a consensus vote is more democratic and fair, but also in this case the final group ranking could have a low rate of acceptance, being supported only by a relative majority. According to Le Pira et al. (2016b), the optimal solution should be based on a mixed procedure that combines mathematical aggregations with consensus building, through an interaction process among stakeholders that facilitates a convergence of opinions, in a way to increase the acceptability of the final results while at the same time guaranteeing transparency of the decision process. In this paper, a comparison among mathematical aggregation of priorities and a consensus vote was performed to verify the differences between the two alternative rankings and the correspondence with stakeholder preferences.

3. Case study

3.1. The decision-making context

Catania is a city of about 300.000 inhabitants, located in the eastern part of Sicily (Italy); it has an area of about 183 km^2 and a population density of 1.754,54 inhabitants/km^2. It is part of a greater Metropolitan Area (750.000 inhabitants), which includes the main municipality and 26 surrounding urban centers, some of which constitute a whole urban fabric with Catania (Ignaccolo et al., 2016).

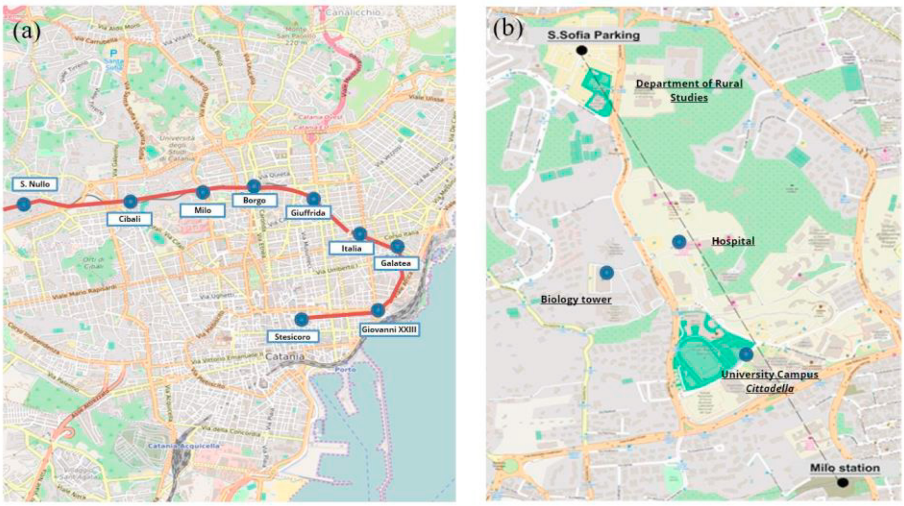

Fig. 2 (a) territorial framework with the metro line; (b) area of intervention (from Milo station to S.Sofia parking) (own setup).

The main city (Fig. 2a) contains most of the working activities, mixed with residential areas. With reference to the urban area, the transport service is provided by 51 bus lines, a Shuttle line (called ALIBUS) connecting the city center with the airport and a second rapid bus (called BRT1) connecting a parking located in the northern part of the urban area with one of the main squares in the historical center. An urban metro line currently links the port of the city (which is very close to the historical center) with the area immediately out of the historical center, from which it continues as a surface long-distance line. The line is expected in the next years to grow from 7 km to 11 km, connecting the city center with the peripheral areas. A new subway station, named "Milo", has been recently opened. Its position will make it the closest station to an area where important University sites, health services and a parkand-ride facility (S. Sofia parking) are located (Fig. 2b). Due to slope and distance between the station and the University sites, a new dedicated hectometric transit service linking the two transport nodes is under evaluation. Four different transit alternatives are proposed (Ignaccolo et al., 2017): a *bus*, which is the most popular mean of collective public transport in our cities with a well-established technology; a *Minimetro* or *people mover*, which is a modern automatic rail automatic system, where vehicles are usually equipped with rubber tires circulating on metallic or concrete guides; a *monorail* called *"Etna Rail"*, which has been designed for the metropolitan area of Catania, including 3 different lines, with one tangential to the study area; a *ropeway*, which falls into the category of cable transport and is the most common technology used to connect areas divided by a very high slope.

A first decision-making hierarchy was built based on the result of in-depth interviews with five key stakeholders, representing the main interest groups affected by the intervention: (1) the University of Catania, (2) the urban bus transit company (Azienda Metropolitana Trasporti – AMT Catania), (3) the University Students' Council, (4) the Municipality of Catania and (5) the metro rail company (FCE – Ferrovia Circumetnea) (Ignaccolo et al., 2017). A Web GIS map[‡] has been shown to the stakeholders with a representation of the main impacts of the four different alternatives. Stakeholders were individually interviewed, by asking them if they agreed on the importance of the intervention and then to assign an importance level to four different impacts of the alternatives under consideration, i.e. transport, economic, social and environmental impact. In the final part of the interview they have been asked to perform a SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis for each of the alternatives, in order to elicit their different opinions in terms of strengths (i.e. internal features of the project providing an advantage over others), weaknesses (i.e. inherent characteristics that place the project at a disadvantage relative to others), opportunities (i.e. external issues that the project could benefit of), threats (i.e. external elements that could cause failures of the project). From the results of the survey, it was possible to derive the main elements (i.e. sub-criteria) to build a first decision-making hierarchy. Table 1 schematically summarizes the elements that compose the criteria/sub-criteria levels of the hierarchy, where the goal is the choice of the best transport system and the four alternatives are at the bottom level (more details can be found in Ignaccolo et al., 2017).

Table 1. Criteria and sub-criteria identified in the process

Criteria	Sub-criteria
Transport	Accessibility; Travel time; Frequency; Comfort
Economic	Implementation cost; Economic Risk; Management cost
Environmental	Air pollution; Noise Pollution; Visual Intrusion
Social	Acceptability; Urban requalification; Perceived Security

3.2. The participation experiment

In order to test the decision-making hierarchy and evaluate alternatives from a multi-stakeholder multi-criteria perspective, a participation experiment was set up, by involving University students in a role-playing game. Such experiment has been arranged as a preliminary test of the procedure that, in future, will be carried out with real stakeholders. Forty students of the "Transport Systems" class of the Master Course in "Environmental Engineering" of the University of Catania were involved in the experiment, which took place between May and June 2016. A total of 5 sessions of 2-3 hours each were organized. The students were trained on the complexity of decision-making about transport systems and the role of multicriteria decision technique to support decision-making (two sessions). Two sessions were dedicated to the description of the case study with a detailed analysis of the four transit alternatives. In the last session, the actual participation experiment took place. They were divided in five groups, each of them representing one of the key stakeholders described in section 3.1. The results of the in-depth interviews were provided to them in order to make them identify with the specific role. AHP was performed using the software SuperDecisions© (www.superdecisions.com). The first step was to validate the previously developed hierarchy. In this respect, the students shared all the criteria and confirmed it, as shown in Fig. 3. Then, the groups were asked to make pairwise comparisons for each level of the hierarchy. The inconsistency of judgments was constantly monitored and kept to the minimum.

[‡] The WebGIS map with an example of the survey proposed to the stakeholders can be found at the following website: http://transportmaps.altervista.org/LinkMiloSSofia/index.html

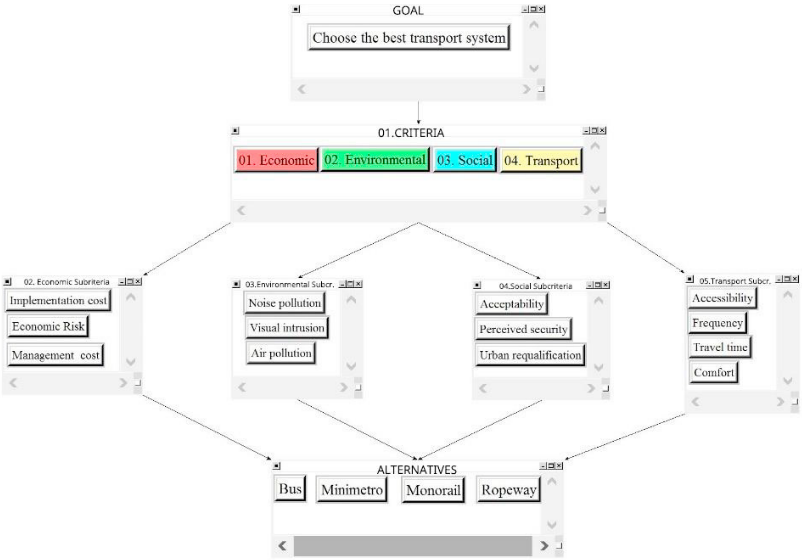

Fig. 3. Hierarchy of the decision problem in SuperDecisions.

4. Results

4.1. Priorities results of the participation experiment

Results of the pairwise comparisons on criteria and sub-criteria for the five groups are shown in Fig. 4:

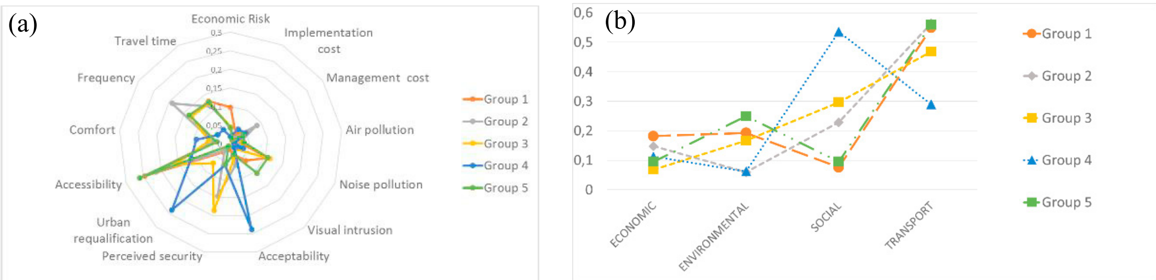

Fig. 4. AHP results: (a) sub-criteria priorities and (b) criteria priorities.

The first group (group 1), which played the role of the University of Catania (and, specifically, the Rector's delegate in charge for mobility management), gave more importance to the transport impact (criterion) and, in particular, to accessibility, travel time and frequency (sub-criteria). The second group (group 2), representing the urban bus transit company (AMT), also considered the transportation impact as the most important aspect followed by the social one, especially in terms of accessibility, frequency and perceived security of each transport system alternative. The third group (group 3), playing the role of a student representative of the University Student's Council, considered important the transport and social impacts, in terms of perceived security, accessibility and travel time. The fourth group (group 4), representing the Municipality of Catania, assigned the highest level of importance to the social criterion, in particular in terms of acceptability of the proposed solutions and urban requalification of the surrounding areas. The last group (group 5), representing the metro rail company (FCE), gave priority to transport impact, in particular in terms of accessibility, followed by the environmental impact referred to noise pollution and visual intrusion. As can be noticed in Fig. 4, there is some heterogeneity in the judgements, even if accessibility is one of the overall most ranked sub-criterion. Globally, transport impacts are considered more important, followed by the social, environmental and economic ones (Fig. 5a). These results are clearly in line with the preferences that key stakeholders expressed in the in-depth interviews, showing that students were able to play the roles assigned to them. Finally, priority rankings of alternatives for each group are shown in Fig. 5b.

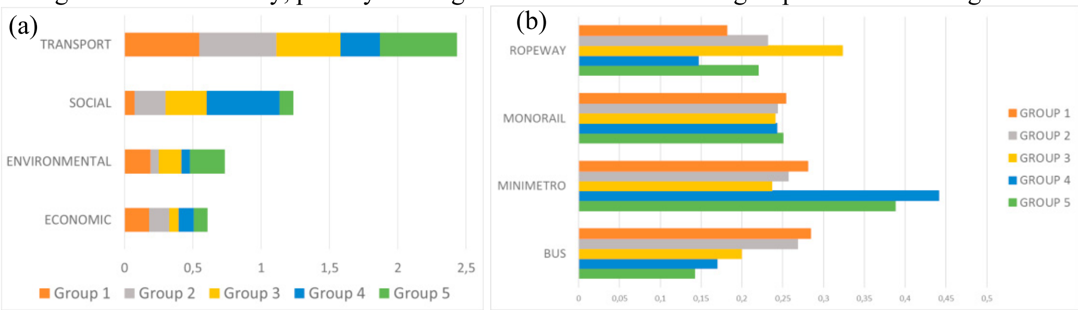

Fig. 5. Priority results of (a) criteria and (b) alternatives.

Minimetro shows the highest priority for group 4 (i.e. Municipality of Catania) and group 5 (i.e. FCE), while *ropeway* is the first ranked for group 3 (i.e. Student's Council). On the contrary, priority rankings for group 1 and 2 (University of Catania and AMT) are quite "flattened". It is worthy of notice that these results rely on students' perceptions about the impacts of each alternative on the different dimensions and that they are not the output of a technical evaluation. Nevertheless, they were well informed about the alternative transport systems and they had a background in transport engineering, therefore they can be considered "sophisticated stakeholders" (Le Pira et al., 2015). In the following, aggregation of individual priorities has been performed and compared with the result of a consensus vote, to derive a collective decision as an output of the AHP procedure.

4.2. Consensus vote vs mathematical aggregation

The last step was to analyse the final results via a consultation process with the five groups representing the key stakeholders. The main aim was to reach an agreement on the best transit alternative. After a discussion about the different priority rankings derived from the five AHP, the whole group decided that there might be a best short-period solution and a best long-period solution. In this respect, *bus* would be a good solution in the short period while *Minimetro* would be the best solution in the long period. This can represent an input for discussion with real stakeholders in the future. The obtained results depend on the sample considered in this study and they could be different if other groups of students were considered. In a real participation process the consensus vote can be altered by more influencing stakeholders, so a stakeholder analysis can be helpful to gain insight into their power/influence in the decision-making process. Subsequently, a mathematical aggregation of the five priority rankings was done using the geometric mean method, in order to make a comparison with the decision for the long period emerged from the discussion. Results confirm that the best solution is the *Minimetro*. However, as opposed to the consensus vote, the second solution is *monorail*, followed by *ropeway* and, lastly, *bus*. This demonstrates that a mathematical aggregation of individual priorities is not always appropriate to obtain a group decision representative of stakeholder interests. Aggregation of individual judgments or, if possible, a consensus vote is to be preferred. Nevertheless, the group ranking derived from simple priority aggregation confirmed what stakeholders evaluated as the best solution, therefore it can be useful to have a global vision of stakeholder preferences.

5. Conclusions

This paper combines Analytic Hierarchy Process (AHP) with role-playing games to support stakeholder engagement in complex transport decisions where students played the roles of key stakeholders, representing their interests with the final aim to select the best transit system solution out of four possible alternatives. AHP is widely used to support transport decision-making processes requiring the evaluation of alternatives from multiple criteria. Its usefulness for group decision-making is here demonstrated, since it allows to elicit and compare stakeholder individual judgments and pave the way for consensus building among stakeholders. The procedure here described is part of a wider participation process, with the final aim of selecting the best transit alternatives adopting a multi-stakeholder multicriteria perspective. After a consultation with key stakeholders and a first evaluation of alternatives, a public consultation will be performed via a stated preference survey, to collect citizen preferences for different transport system alternative configurations. The overall goal is to have enough information to guide the final decision, which should be based both on the results of technical evaluations and the one of the participation process.

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