October 2019

Optimising participatory budget allocation: the Decidim use case*

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Abstract. With the advent of Internet, on-line technologies have been adopted for offering e-government services. Recently, information services are also being complemented with participatory platforms, which try to bridge the gap between citizens and government in decision making processes. However, ensuring best decision making becomes crucial to engage citizens with their (national or local) administrations. This paper proposes the application of optimisation techniques to participatory budget allocation processes, which are currently based on vote-counting. In particular, we formalize the problem of selecting the best combination of proposals in terms of their social support and available budget. Moreover, we analyse the case of budget allocation in Decidim Barcelona, an online platform for citizen participation. We encode the problem as a linear program and test it in two local participatory budget allocation pilots. Results illustrate how our optimisation approach outperforms the standard proposal selection method in the total number of gathered supports, the number of selected proposals as well as in the allocated budget.

Keywords. e-governance, participation platform, budget allocation, optimisation, linear programming, AI application.

1. Introduction

Representative democracy can be seen as a procedural structure limiting the incidence of citizens in political life to a mere government election every four years. This induces a gap between citizens and their governments that may even lead to a distrust on political institutions such as the government –be it local or national– or the parliament. Alternatively, participatory democracy pursues to create opportunities for all members of a population to make meaningful contributions to (political) decision-making.

As technology is nowadays shaping our societies –enabling social communities and enhancing disruptive concepts such as social and democratic innovation– it is also bringing a paradigm shift in e-government towards citizen participation. This has lead to the appearance of new e-participation and e-governance ICT systems [21,9,14]. Thus, several platforms have appeared to help citizens to take part in political institutions. Some platforms act at a national level, such as New Zealand's Ministry of Justice consultation

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*This research has received the support of the Laboratori d'Innovació Democràtica and funding from the Ajuntament de Barcelona through the Fundació Solidaritat UB as well as from projects 2017 SGR 172, 2017 SGR 341, and AI4EU (H2020-825619).

hub [16] or France's Parlement et Citoyens [11] platform. These platforms allow citizens to discuss matters of national interest –such as family violence law [15] or the state pension reform [13]– and pose legislative petitions (e.g. on euthanasia [10]) to their parliament members. Other platforms operate locally. Thus, we can find examples in Better Reykjavik [19], Decide Madrid [17], or Decidim Barcelona [6], where citizens are given the chance to present and debate their ideas on issues regarding their cities or even specific neighbourhoods.

Although these platforms offer a great tool for citizens to take part in their government's decisions, standard participatory budget allocation processes can be improved. Participatory budget allocation (or participatory budgeting) is a democratic process in which community members decide how to spend part of a public budget. It deepens democracy, builds stronger communities, and creates a more equitable distribution of public resources [7]. Typically, this process is based on vote-counting. Figure 1 illustrates the standard "rank and select" method by considering an overall budget of 9 and four different citizen proposals (A, B, C, D). Citizens vote for these proposals, which have specific costs. Subsequently, proposals are ranked based on their gathered support (i.e., in decreasing order of number of votes: B, A, C, D on the left of Fig. 1) and are selected starting from the top ranked until there is no budget left for the next proposal in the ranking. In the example, just proposal B is selected, since adding next proposal A would exceed the available budget: cost(A+B)=12 $>$ 9. However, there are other combinations of proposals that collect more supports. Indeed, the combination of B+C+D gathers 10 supports at a total cost of 9 (see right-hand side of Fig. 1). Thus, although this "rank and select" is intuitive, the selection method can be improved. In particular, we advocate for optimising proposal selection to maximise overall citizen support.

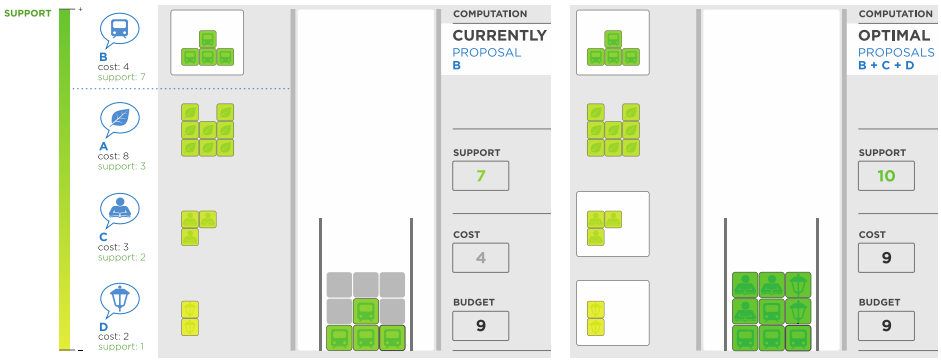


Figure 1. Differences between current "rank and select" (on the left) and optimisation (on the right). Current method selects the first proposal (B) and since it has no budget for the second one stops, gathering 7 supports. Optimisation considers different combinations to select the best one (B+C+D), resulting in 10 supports.

This paper describes an optimisation approach for the improvement of the proposal selection method in participatory budgeting. The work has been conducted in the context of the `Decidim Intel.ligent` research project, performed in collaboration with the Decidim citizen participation platform [8], with the aim of increasing citizen satisfaction and sense of involvement. We test our approach in two participatory budgeting pilot tests that were conducted within the Decidim Barcelona [6] platform in two different neighbourhoods [3,4]. Results show that optimisation outperforms the "rank and select"

method in both tests, not only in the number of gathered supports (which was expected), but also in the number of selected proposals and the allocated budget.

We structure the paper as follows: Section 2 analyses the current "rank and select" methodology and argues both theoretically as well as in real scenarios the possible improvements. Section 3 adapts the previous work on norm optimisation to suit proposal optimisation in budget allocation processes, thus formalising the problem. Next, Section 4 describes several experiments on real-case data to show the benefits of our proposed method. Finally, Section 6 concludes the paper and proposes ideas for future work.

2. A critical analysis of current practices in participatory budgeting

Decision making in participatory budgeting amounts to a collective selection of a set of project proposals given some available funds. As for 2019, participatory budgeting has spread to over 3,000 cities around the world and most processes use between 1-15% of their local city budget [7]. Here we focus on Barcelona.

Periodically, the municipal government of Barcelona allocates a budget to be spent in proposals decided in participatory processes. Roughly, the participatory budgeting process consist of the following phases [5]. First, citizens propose their projects on the Decidim Barcelona website [6]. Once the proposal presentation phase is finished, the proposals must undergo an initial technical validation, so that proposals that are not legal nor technically viable are discarded. Then, the remaining proposals enter a debate phase where citizens are able to support proposals and provide arguments for or against them. Afterwards, most supported proposals go through a second technical evaluation that assigns costs to them so that they can be presented for public voting. Citizens are able to cast their votes for their preferred proposals by means of a shopping cart. Specifically, users can add to the cart their preferred proposals as long as they do not exceed the available budget. Once the voting term expires, the "rank and select" method previously introduced is applied so that the proposals are ranked and selected in order until the budget left is not enough to cover the cost of the next proposal in the ranking. Finally, for the sake of transparency, citizens can subsequently monitor the implementation progress of selected proposals.

Although this process works reasonably well, we argue that there is some room for improvement. Firstly, these phases involve a good deal of manual intervention, and thus, the process would benefit from introducing some automatic selection procedures that scale well with the number of proposals. Secondly, as previously stated, the current selection process –i.e., the "rank and select"– can be numerically optimised, so that we can guarantee that the set of selected proposals actually corresponds to the best one.

Optimisation gain becomes most apparent when dealing with proposals that are very expensive if compared to the available budget. In this case, very few proposals will be selected and since the process ends when the next ranked proposal has a higher cost than the available budget, chances are high that the leftover budget is significant. Instead, this leftover could be spent in some of the remaining proposals. Moreover, recalling the example in Figure 1, this situation worsens when just the top ranked proposals are expensive and their support is similar to that of other (cheaper) proposals. In this case, proposals with high cost and high support are selected while other proposals with similar support at a fraction of the cost are left out. Note also that selecting only the top-ranked

proposals has the undesirable consequence of penalising small proposals with small cost and small impact. For example, routine repairs of public spaces (like fixing a tile on a street), will only impact people living in (or transiting) that space. Since these kind of proposals have low impact, less people are likely to support them, thus the "rank and select" method will scarcely choose them despite their low cost and relative support. Thus, we argue that while "rank and select" only considers the top ranked proposals and neglects these small impact interventions, optimisation would be less prone to discard modest proposals.

Although previous discussion may seem negligible, these situations can easily happen in practice. Here we analyse two participatory budgeting pilot tests conducted in 2016 and 2017 in two neighbourhoods of Barcelona, namely Eixample and Gràcia. Next, we will explain some of these undesired situations while introducing the Eixample pilot.

Rank	Proposal summary	Cost	Votes
1	Commercial vehicles contamination reduction plan in the neighbourhood	52.500 €	201
2	Architectural barrier reduction	26.000 €	199
3	Green schools	17.800 €	196
4	Air quality information campaign	15.000 €	192
5	Study on alternative housing to social flats in l'Eixample	15.000 €	189
6	Mapping of the elders living alone	30.000 €	188
7	Benches on sidewalks for elder people	18.000 €	186
8	Gender-based violence sensitization program for students	16.000 €	180
9	Cultural activities inside Eixample's apartment isles	112.000 €	177
10	Community process for agro-alimentary projects	26.200 €	172
11	Accessibility to Eixample's cultural heritage	9.000 €	172
12	Cooperative, social, and solidary schools	40.500 €	172
13	Private transport contamination sensitization program	18.000 €	168
14	Youth project	7.000 €	166
15	Air quality sensitization campaign on the schools	16.000 €	151
16	Nocturnal noise study	4.000 €	148
17	Project on detection and prevention of homophobia at schools	63.000 €	143
18	Street artists space	30.500 €	133
19	Feminist Eixample	80.000 €	122
20	Sociocultural project at Sant Antoni market	15.000 €	121
21	House front decoration contest	40.000 €	96
22	Mapping of unused locals at Sant Antoni	250.000 €	93

Table 1. Results of the participatory budgeting process in the Eixample neighbourhood [1]. The available budget was 500.000€, green proposals where accepted, red ones denied by using the "rank and select" method.

Table 1 shows the proposals submitted to vote, their associated cost, the votes received (and corresponding ranking), and the relation of accepted and rejected proposals for the Eixample pilot test. In this case, the local council set a budget of 500.000 €. Since the table is already ordered by ranking, selection starts at the top and ends when the budget is not enough to cover the expenses of the next ranked proposal. In this case, the budget was relatively high, and hence, no notorious problems came about when selecting first 17 proposals. However, notice that problems may have occurred had the budget been less generous. As previously mentioned, the most problematic scenario raises when top-ranked proposals are very expensive and have small differences in votes with other proposals. In this case notice that the top proposal cost doubles the second one whilst just having 2 additional votes (see the first two rows in Table 1). Therefore, if the budget was

60.000€ the "rank and select" approach would just select the first proposal neglecting any other proposal. This is so because the second ranked proposal costs 26000€ while there are just 7500€ left. In this manner, selecting the first proposal would gather 201 supports whereas selecting proposals 2,3,4 is a better solution since it accumulates 587 supports and still fits in the budget. Nevertheless, in this case even a better solution is possible. Indeed, the optimal solution consists on selecting proposals 2, 3, 11, 16, which gather 715 supports. That is possible because proposal 11 is substantially cheaper than proposal 4 and has a similar amount of votes. In fact, selecting it gives us sufficient left-over budget to also select proposal 16. As a consequence, we have seen that selecting the set of proposals amounting the highest number of supports may not be an easy task but it can be accomplished by means of optimisation.

Rank	Proposal summary	Cost	Votes
1	Caring about caregivers	14.000 €	168
2	Social and solidary economy at the palm of your hand	26.000 €	161
3	System to share resources between organisations	9.500 €	160
4	Youth scenic arts laboratory	24.000 €	160
5	Neighbourhood live art exhibit	23.000 €	144
6	Social and solidary economy routes in Gracia	24.000 €	139
7	Meeting and empowering spaces for elder women	20.500 €	130
8	Construction of "the beast" and the "big heads"	13.000 €	114
9	Woman perspective walk	8.500 €	102
10	Hidden knowledges	39.500 €	88
11	Cooperative dialogs	15.000 €	87
12	Gracia's women memory	28.000 €	76
13	Gracia's women month	36.000 €	74
14	Book publication	18.000 €	60

Table 2. Results of the participatory budgeting process in the Gràcia neighbourhood (for simplicity, categories are not displayed). "Rank and select" accepted green proposals and denied red ones for a budget of 150.000€.

Table 2 illustrates how the Gràcia neighbourhood pilot test [2] performed similarly. Thus, the actual budget of 150.000 € prevents the "rank and select" method from choosing proposal 8, but the leftover budget of 9.000 € would allow for the selection of proposal 9. Again, differences with the optimisation become larger for other budgets. For instance, considering a budget of 40.000 €, the "rank and select" method just returns proposals 1, 2 accumulating 329 supports whereas optimisation selects proposals 1, 3, 8 gathering 442 supports, which amounts for a 34.3% increase in support.

It may be worth mentioning that when optimising we can also consider the relations between proposals, such as incompatibility (when two proposals cannot be accepted at once, such as devoting a road line for busses or for bicycles), substitutability (when two proposals are interchangeable, e.g.: build a bicycle line or devote a road line to bicycles) or generalisation (when a proposal is more general than a specific proposal, e.g. when one applies to a district and the other to the whole city). However, current participatory budgeting initiatives do not consider such relationships. On the other hand, voting over combinations of proposals may seem useful to cope with proposal dependencies, but it would not scale as that would mean to have $2^{|P|}$ possible combinations.

3. Participatory budgeting optimisation

Given a set of candidate proposals P and an available budget b, participatory budgeting corresponds to the process for selecting a subset of proposals $P' \subseteq P$ based on citizen supports. Therefore, we can optimise this process by selecting those proposals P^* that together gather as much citizen support as possible for a budget b. Formally, our problem is that of finding the subset $P^* \subseteq P$ that maximixes the aggregated citizen support for a given budget. In fact, we can cast this optimisation problem as a knapsack problem [20] in combinatorial optimisation. Since it is an NP-Hard problem, we encode it as linear program and subsequently solve it with state-of-the-art solvers such as CPLEX [12] or Gurobi [18].

We start encoding the linear program by defining a binary decision variable to represent each proposal $p_i \in P$ selection. In this manner, a binary decision variable $x_i \in \{0,1\}$ will take a value of 1 ($x_i = 1$) if proposal p_i is selected whereas it will become zero ($x_i = 0$) if p_i is discarded.

Next, we specify the objective function in terms of proposals' citizen support. We define the support function of a proposal $p \in P$ as $support(p) = \#votes\_received$. We name "Citizen Satisfaction", the aggregated support of the selected proposals, formally:

$$Citizen\ Satisfaction = \frac{\sum_{p_i \in P} x_i \cdot support(p_i)}{\sum_{p_i \in P} support(p_i)} \tag{1}$$

Thus, we reword the goal of the optimisation as that of *maximising citizen satisfaction*:

$$Maximise\Big(\frac{\sum_{p_i \in P} x_i \cdot support(p_i)}{\sum_{p_i \in P} support(p_i)}\Big) \tag{2}$$

subject to the following constraints:

- Limited budget constraint. The cost of all selected proposals cannot surpass the fixed available budget b: $\sum_{i=0}^{|P|} c(p_i) \cdot x_i \leq b$, where $c(p_i)$ stands for the development cost for proposal $p_i \in P$.
- All decision variables must be binary: $x_i \in \{0,1\}, 1 \leq i \leq |P|$.
- Relationship constraints. As mentioned in Section 2, proposals may be related in ways that should be considered when computing its selection. Thus, two mutually exclusive or substitutable proposals cannot be selected at once: $x_i + x_j \leq 1, \forall (x_i, x_j) \in R_x$ and $x_i + x_j \leq 1, \forall (x_i, x_j) \in R_s$, where R_x and R_s define such relationships. Moreover, considering a genearalisation relationship, a proposal should not be selected together with any of its successors and we favour it over selecting all its direct successors (i.e., children) provided that there are more than one: $x_i + x_j \leq 1, \forall x_j \in Successors(x_i)$ and If $|Children(p_i)| > 1$ then $\sum_{p_j \in Children(p_i)} x_j < |Children(p_i)|, 1 \leq i \leq |P|$.

4. Experimental Results

This section compares our optimisation approach with the "rank and select" method, which is extensively used in participatory budgeting. Comparison considers both Eixam-

ple [3] and Gracia [4] pilot tests at hand and it is performed in terms of: citizen satisfaction; number of selected proposals; and allocated budget[2].

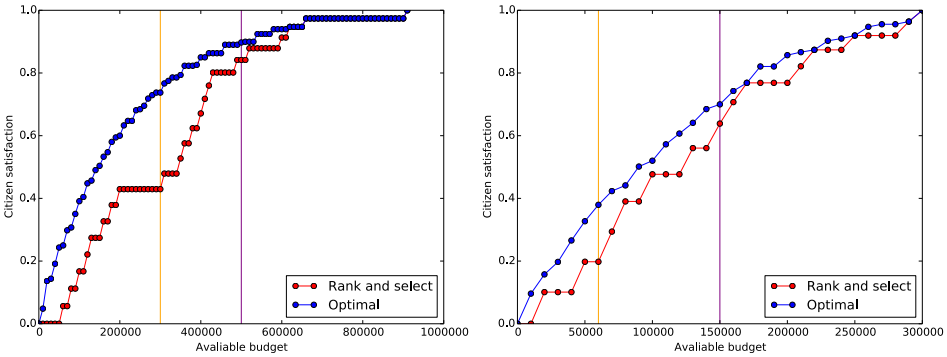
Firstly, we compare the results in terms of citizen satisfaction, which, as Eq. 1 details, corresponds to the (normalised) total number of supports received by selected proposals. As for the Eixample pilot test, recall from Section 2 that it had a budget of 500.000 € and that "rank and select" method selected the 17 first-ranked proposals in Table 1. This corresponds to a citizen satisfaction of 84,15% (3000 supports of the 3565 possible). Alternatively, our optimisation method is able to accumulate a slightly higher citizen satisfaction of 89,73% (3199 supports of the 3565 possible) by selecting proposals 18, 19 and 20 instead of proposal 9. Similarly, Gràcia had a budget of 150000€, and this resulted in a citizen satisfaction of 63,86% (1062 supports of the 1663 possible) for the "rank and select" method (see Table 2) whereas our optimisation method increases it to 70% (1164 supports of the 1663 possible).

In order to assess the full potential advantage of our method, further than just limiting our comparison to the real case of the specific budget that these two pilots had awarded, we consider a range of hypothetic scenarios with different budgets. In this manner, for each pilot, we start by considering a budget of 0 (where no proposals can be selected), and take budget increments of 10.000€ until we reach a budget where all proposals can be selected (that is, 910.000 € in the case of the Eixample and 300.000€ for Gràcia). Figures 2a) and 2b) plot, respectively, the results for the Eixample and the Gràcia neighbourhoods. For each figure, the x-axis corresponds to the range of available budgets and the y-axis to the accumulated citizen satisfaction of the selected proposals. Moreover, the blue line represents the results using optimisation, while the red line depicts the results using current "rank and select" method. The purple vertical line corresponds to the previous method comparison on the real cases. By examining these plots, the improvement of our optimisation method becomes apparent when considering the large gap between the blue and red curves.

Although both methods return similar solutions when considering large budgets (since most proposals can be selected), differences become notorious for small and medium budgets. Indeed, we find the largest difference for b = 300.000€ in the Eixample (see the orange vertical line in Figure 2a)), when the difference becomes as large as 30,8% citizen satisfaction (or, in other words, 1098 supports more, which account for an increase of 71,7 %). This difference can be explained in terms of what Section 2 discussed about proposals having similar number of votes and very different costs (being the most expensive proposals slightly preferred over the others), since this is when the current method performs poorest. Specifically, the "rank and select" method chooses the 8 top-ranked proposals in Table 1 because they accumulate a cost of 190300€ and the remaining 109700€ are not enough to cover the cost of 12000€ of proposal 9. Instead, our optimisation selects, in addition to proposals 1-8, proposals 10, 11, 13-16, and 20. As for Gràcia, we get the biggest improvement for a budget b = 60.000€ (see the orange vertical line Figure 2b)), when the difference becomes as large as 18,16% of citizen satisfaction (or, in other words, 302 supports more), which accounts for an increase of 91,8%.

Regarding the number of selected proposals, our method selects a higher or equal number of proposals than the "rank and select" method for the two studied pilots. Figures 3a) and 3b) respectively report the number of selected proposals for the Eixample and

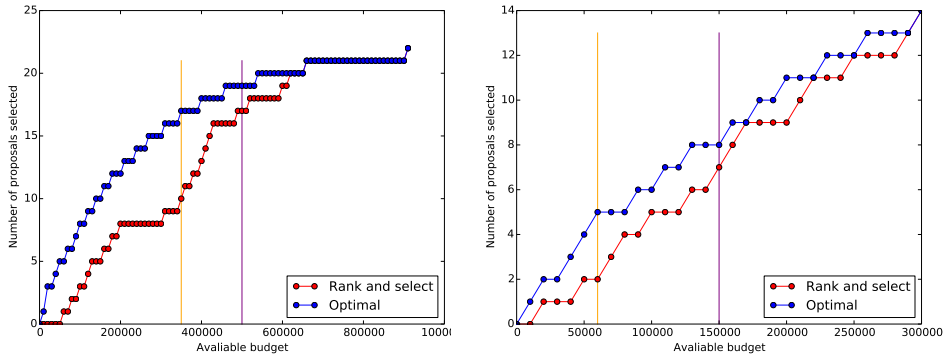
[2]Source code available at: https://bitbucket.org/marcserr/decidimoptim



(a) Eixample (b) Gràcia

Figure 2. Citizen satisfaction (aggregated number of votes gathered by selected proposals) for two participatory budgeting pilot tests: a) Eixample and b) Gràcia. X-axis corresponds to different budgets, the purple vertical line represents the available budget actually awarded in the pilot and the orange one the maximum difference between both methods.

Gracia participatory budgetting processes considering the same range of budgets as in previous figures. As before, our method outperforms most "rank and select" in Eixample when b = 300.000€, since it selects the 7 additional proposals previously mentioned (increasing an 87.5%), and in Gracia when b = 60.000€, where it selects 5 proposals instead of 2 (which amounts of an increase of 150%). On average, optimisation has achieved to select 2,76 proposals more than "rank and select" in the case of Eixample, and 1,16 in the case of Gracia.



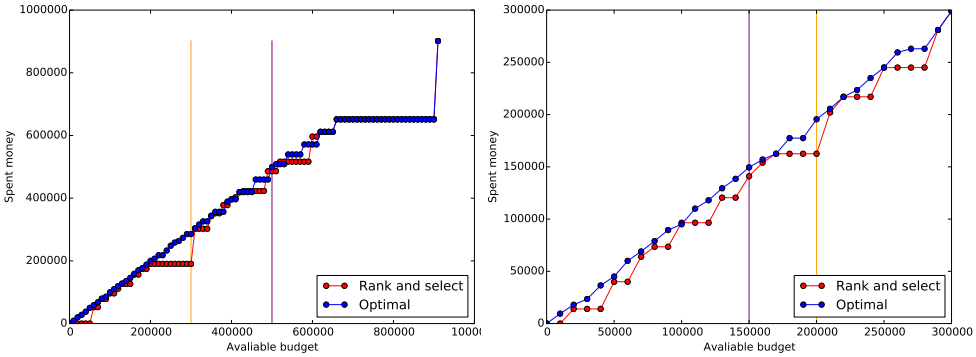
(a) Eixample (b) Gràcia

Figure 3. Number of selected proposals in a) Eixample and b) Gràcia. The purple vertical line represents the actual available budget and the orange one the maximum difference between both methods.

In terms of the total allocated budget, Figure 4a) shows that our method allocates budget much better in some particular cases (see budgets 0-50.000€; 200.000-300.000€; 460.000-480.000€; 540.000-590.000€), while Figure 4b) illustrates that the optimisation method performs slightly better allocating most of the considered budgets in the case

of Gràcia. On average, optimisation has been able to allocate 12.639 € more than "rank and select" in the case of Eixample, and 10.016 € in the case of Gràcia.

Note that optimisation is able to produce better solutions by means of augmenting the granularity (in terms of cost) of its solutions. By selecting cheaper proposals there is more leftover budget to select more proposals. Thus, thanks to granularity we not only increase the total supports but also experience some beneficial side effects, such as, higher number of selected proposals and a better fit to the budget (less leftover).



(a) Eixample (b) Gràcia

Figure 4. Allocated budget (sum of the cost of all proposals) for different budgets. The purple line represents the budget used in reality, while the orange line marks the largest difference between both methods.

5. Discussion

Interestingly, we believe that our domain of study opens challenging opportunities for AI research that go beyond the initial results presented in this paper. First, since citizens issue their proposals in natural language, there is the issue of providing support to the city hall technicians to identify similar proposals, and even to eventually recommend ways of merging proposals. Moreover, further relationships between proposals may hold and must be also detected and taken into account: some proposals might be more general than others, some might be mutually exclusive (e.g. separate proposals may request to build a park and a swimming pool in the very same public space, and hence both cannot be accepted), or others may represent alternatives, notice that our model in Section 3 already shows how to accommodate such types of constraints. City hall technicians will benefit from decision support to find all such relationships. This represents an excellent opportunity to apply NLP techniques, and in particular text mining techniques. Second, the debate phase involving citizens provides an excellent opportunity to carry out sentiment analysis and learn citizens' preferences and needs (e.g. environment protection comes before culture), and even their *values* in an ethical sense.

6. Conclusions and future work

With the aim of bridging the gap between citizens and government in decision making processes, we propose the application of optimisation techniques (via linear programming) to participatory budgeting. In particular, we formalise the problem of selecting the best combination of proposals in terms of their social support and available budget.

We then apply this method to real case scenarios of the Decidim Barcelona platform and compare the results between the "rank and select" method used and our proposed optimisation. Results illustrate how our optimisation approach outperforms the standard proposal selection method in the total number of gathered supports (up to an increase of 91,8%), the number of selected proposals (accepting up to 150% more demands from the citizens) as well as in the allocated budget, which allows for less leftover. As future work, since we are aware that governments may be concerned about the alignment of the selected proposals with their strategic plans, we plan to include general actuation guidelines as preference criteria in the optimisation process.

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