

Knapsack Voting

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Overview

Knapsack Voting

- Introduces definitions, theorems, and related concepts to knapsack voting
- cursory look at preliminary trial
- Focus on definitions and propositions

Budget Aggregation via Knapsack Voting: Welfare-maximization and Strategy-proofness

- Summarizes definitions, theorems, and ideas from first paper
- Analyzes data from digital voting platform
- Split focus on definitions and empirical results

Background – Participatory Budgeting

- Residents vote on how to divide government's total budget between different proposals

State of Maine Sample Ballot
Democratic Primary Election, June 12, 2018
for

Instructions to Voters

To vote, fill in the oval like this

To rank your candidate choices, fill in the oval:

- In the 1st column for your 1st choice candidate.
- In the 2nd column for your 2nd choice candidate, and so on.

Continue until you have ranked as many or as few candidates as you like.

Fill in no more than one oval for each candidate or column.

To rank a write-in candidate, write the person's name in the write-in space and fill in the oval for the ranking of your choice.

Governor	1st Choice	2nd Choice	3rd Choice	4th Choice	5th Choice	6th Choice	7th Choice	8th Choice
Cote, Adam Roland Sanford	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Dion, Donna J. Biddeford	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Dion, Mark N. Portland	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eves, Mark W. North Berwick	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mills, Janet T. Farmington	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Russell, Diane Marie Portland	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sweet, Elizabeth A. Hallowell	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Write-in	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

SOURCE: Maine Secretary of State Office

OFFICIAL BALLOT
MEMPHIS MUNICIPAL ELECTIONS
OCTOBER 6, 2011

INSTRUCTIONS TO VOTER

- TO VOTE** YOU MUST BLACKEN THE OVAL COMPLETELY.
- USE ONLY A NO. 2 PENCIL OR A BLACK OR BLUE PEN.
- TO WRITE-IN** a name, you must blacken the oval to the left of the line provided.
- DO NOT CROSS OUT OR ERASE** - If you change your mind or make a mistake, exchange your ballot for a new one.
- AFTER VOTING** - Insert ballot in the envelope provided and return it to the election office.

CITY OF MEMPHIS	
<p style="text-align: center;">Memphis Mayor Vote for One (1)</p> <p><input type="radio"/> Leo AwGoWhat</p> <p><input type="radio"/> James R. Barbee</p> <p><input type="radio"/> Carlos F. Boyland</p> <p><input type="radio"/> Edmund H. Ford, Sr.</p> <p><input type="radio"/> James Harvey, Sr.</p> <p><input type="radio"/> Robert "Prince Mongo" Hodges</p> <p><input type="radio"/> DeWayne "DEA" Jones</p> <p><input type="radio"/> Marty Memweather</p> <p><input type="radio"/> Kenneth B. Robinson</p> <p><input checked="" type="radio"/> AC Wharton, Jr.</p>	<p style="text-align: center;">City Council Super District 8 Position 2 Vote for One (1)</p> <p><input type="radio"/> Mario Dennis</p> <p><input type="radio"/> Janis Fullilove</p> <p><input checked="" type="radio"/> Rosalyn R. Nichols</p> <p><input type="radio"/> Isaac Wright</p> <p><input type="radio"/> Write-in</p> <hr/> <p style="text-align: center;">City Council Super District 8 Position 3 Vote for One (1)</p> <p><input checked="" type="radio"/> Myron Lowery</p> <p><input type="radio"/> Write-in</p> <hr/> <p style="text-align: center;">City Court Judge Division 1 Vote for One (1)</p> <p><input type="radio"/> Earnestine Hunt Dorse</p> <p><input type="radio"/> Write-in</p> <hr/> <p style="text-align: center;">City Court Judge Division 2 Vote for One (1)</p> <p><input checked="" type="radio"/> Tarik B. Sugarmon</p> <p><input type="radio"/> Write-in</p>

Participatory Budgeting Problem

- The residents of a city are collectively the set of voters .
- They are voting on a set of proposals that they have identified to be worthwhile.
- The proposal has a cost .
- There is a fixed total budget of Dollars.
- The benefit a voter gets from proposal is .
- The set of winning or chosen proposals is .

$$\arg \max_{W \subseteq \mathcal{P}} \sum_{j \in W} \left[\frac{1}{|\mathcal{V}|} \sum_{i \in \mathcal{V}} v_{i,j} \right], \text{ subject to } \sum_{j \in W} c_j \leq B.$$

Average utility

Knapsack Voting

Goel, A., Krishnaswamy, A. K., Sakshuwong, S., and Aitamurto, T. (2015). Knapsack voting. *Collective Intelligence*.

Participatory Budgeting Voting Methods

- Current voting methods:
 - Approval voting (choosing all approved proposals)
 - -approval voting (choosing top- proposals)
- Issues with current voting methods: do not consider proposal costs
- Proposed approaches:
 - Knapsack voting (choosing while considering budget constraints)
 - Value-for-money comparisons (choose proposal that gives the better value among two given proposals)

Knapsack Voting

- Each voter submits a proposal that satisfies the budget constraint .
 - Set of voters
 - Set of proposals
 - Proposal has a cost
 - Fixed total budget of Dollars
- Each proposal receives a score equal to the number of voters that included it in their votes.
- Proposals are chosen in descending order.

Knapsack Voting

- Best response for voter i is the vote that satisfies where
 - Proposal p
 - V_i is the cumulative votes of all voters except i
 - W is the set of winners when i 's vote is added to V_i
 - Benefit a voter i gets from proposal p is $B_i(p)$
 - Set of proposals P
 - Proposal p has a cost $C(p)$
 - Fixed total budget of B Dollars

Knapsack Voting

- Partial strategy-proofness
 - Partial strategy-proofness is new, relaxed notion of strategy-proofness
 - Refers to how a mechanism makes truthful reporting a dominant strategy for those agents whose preference intensities differ sufficiently between any 2 objects

Knapsack Voting

- Partial strategy-proofness theorem: Given a best response if v_i , then there is another best response such that v_i' where
 - Best response for voter i is the vote v_i
 - v_i' is the cumulative votes of all voters except i
 - W the set of winners as determined by v_i'
 - Proposal $p \in W$
 - Set S of proposals
 - Benefit a voter i gets from proposal p is $b_i(p)$
 - Proposal p has a cost $c(p)$

Knapsack Voting

- Corollary 3.3: The partial strategy-proofness theorem fails to hold when each voter submits a β -approval vote (i.e. v_i), and the winning set is constrained by the budget B .
 - Each voter i submits a proposal (x_i, v_i)
- Knapsack voting is provably better than β -approval voting, because knapsack voting can make truthful reporting a dominant strategy.

Value-for-money Comparisons

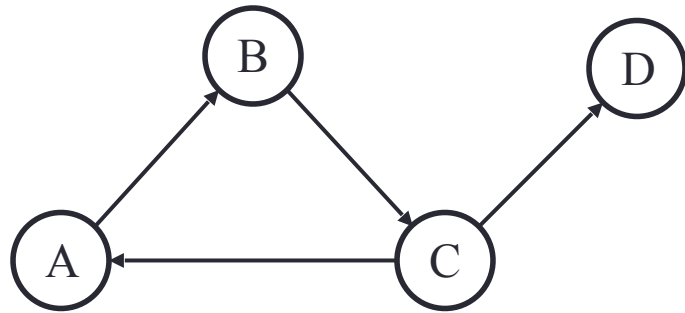
- For each pair of proposals presented to them, the voter is asked to choose a winner .
 - The benefit a voter gets from proposal is .
 - The proposal has a cost .
- Each voter has a fixed size, uniformly random subset of pairs to maintain uniformity.

Value-for-money Comparisons

- The resulting votes are used to calculate a strict rank ordering.
- is a complete directed graph on the set of proposals .
- The weight of each edge is the number of comparisons where j is favored to k .
- Find a strict rank order on that minimizes .
 - Weighted Minimum Feedback Arc Set problem

Weighted Minimum Feedback Arc Set Problem

- A directed graph may have directed cycles or a one-way loop of edges which we want to eliminate.



- What is the fewest number of edges to remove in order to eliminate these loops?
- NP-hard problem but can use LP-relaxation

Linear Programming Relaxation

- Removing the integrality constraint of each variable in a mixed integer linear program
 - A variable may initially be required to be an integer
 - The constraint is relaxed, so the variable can be a fraction instead.
- Transforms an NP-hard problem to a related problem solvable in P time
 - Requires less resources to solve

Preliminary Trial

- Digital voting system for participatory budgeting voting in Vallejo, California from September to October 2014
- Tested value-for-money comparisons voting method with voters
- Use LP-relaxation from Conitzer et al.
 - Changes Weighted Minimum Feedback Arc Set problem to minimizing $\sum_{i \in C} w_i$ which is subject to $\sum_{j \in C} w_j \leq W$, $w_j \geq 0$,
 - G is a complete directed graph on the set of proposals
 - The weight of each edge (j, k) is the number of comparisons where j is favored to k
 - C is set of all cycles in graph

Preliminary Trial

- They found integer-optimal results
- Indicates they may have found the optimal aggregate ranking
- Indicates value-for-money comparisons voting method could potentially be used for participatory budgeting

Budget Aggregation via Knapsack Voting: Welfare-maximization and Strategy-proofness

Goel, A., Krishnaswamy, A.K. and Sakshuwong, S., 2016.
Budget aggregation via knapsack voting: welfare-
maximization and strategy-proofness. *Collective Intelligence*,
pp.783-809.

Knapsack Voting

- Each voter v votes for an allocation x such that where
 - Set of voters
 - Set of proposals
 - Fixed total budget of B Dollars

Introduction

- Redefine Participatory Budgeting Problem and - approval voting
- Knapsack voting
 - Did not discuss how it can be welfare-maximizing
 - No empirical study

Knapsack Voting

- For each p and any w_p , define $u_p(w_p)$.
- The outcome is given by

$$\arg \max_{\sum_{p \in \mathcal{P}} w_p = B} \sum_{p \in \mathcal{P}} \sum_0^{w_p-1} \text{score}(w_p)$$

Knapsack Voting

- They impose some assumptions on voter preferences to maintain strategyproofness
 - Assume natural model of voter utility
 - “Satisfaction” of voter is determined by overlap between preferred budget allocation and final outcome
- Voter utility for election outcome is
 - Voter has preferred allocation that satisfies the budget constraint
 - Outcome of the elections is
 - Voter utility for project is

Knapsack Voting

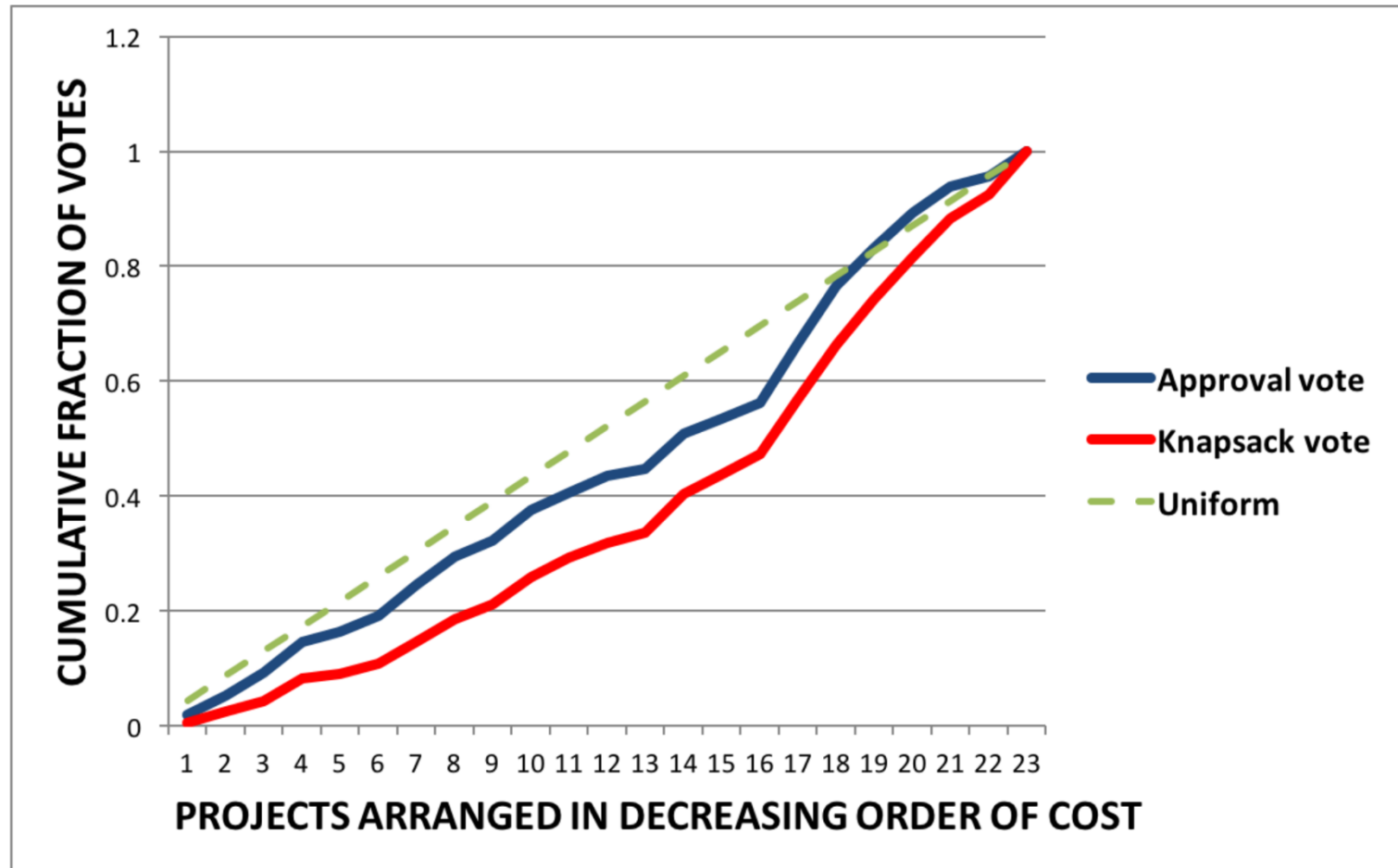
- Knapsack voting is strategy-proof, and its outcome is welfare-maximizing
 - Strategy-proof: the dominant strategy for a voter is voting for their true preferred budget allocation
 - Welfare-maximizing: maximizes the sum of utilities of all voters
- Neither property applies to α -approval voting
- Knapsack voting is superior to α -approval voting under these conditions and assumptions

Empirical Study

- Data from New York District 8 and Cambridge
- Similar trends across all elections
- Had experimental interface for knapsack voting in addition to -approval voting ballot
- -approval voting method biases the outcome towards projects of larger cost compared to knapsack voting
 - Bigger, costlier projects gain more support in -approval voting

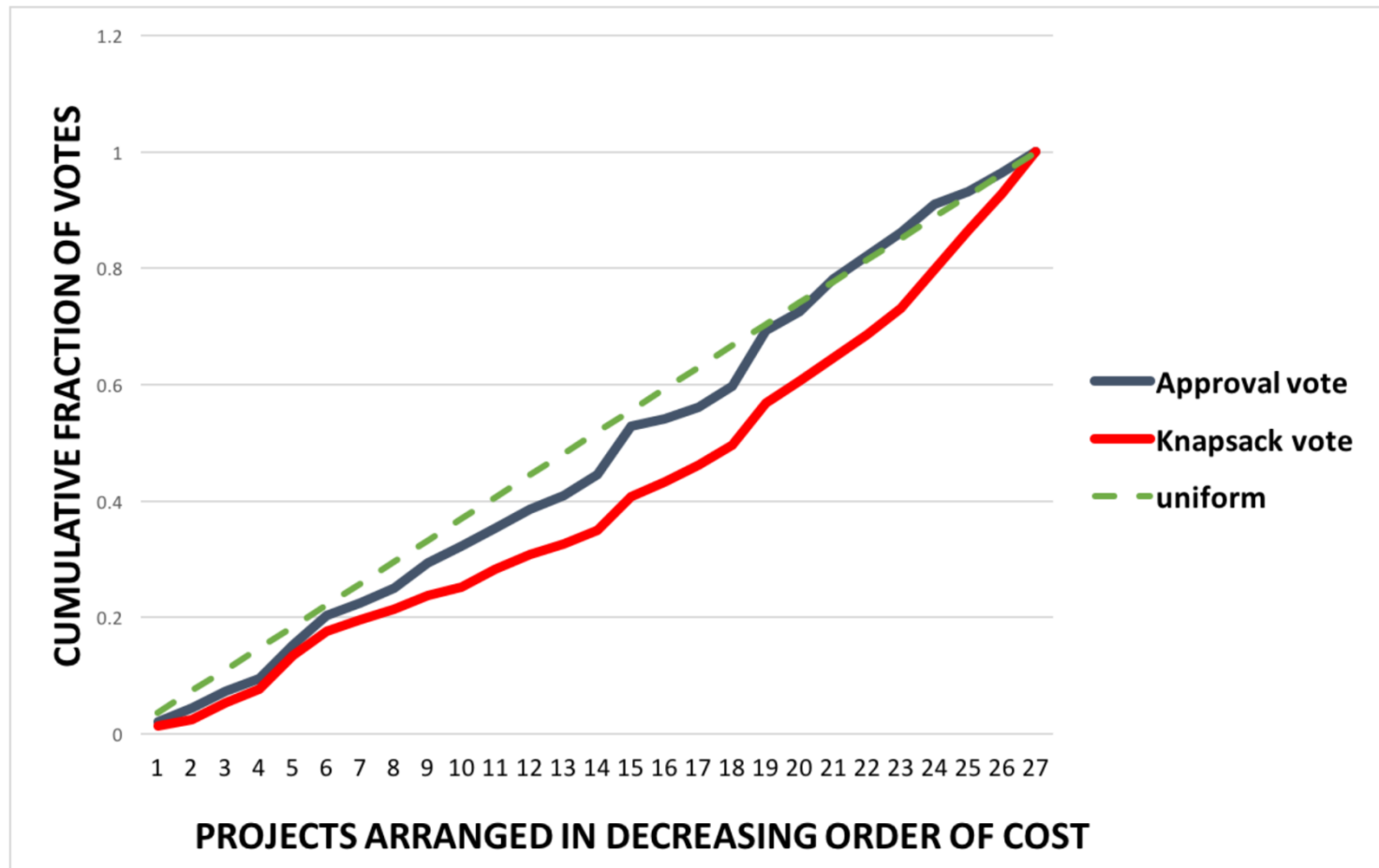
Empirical Study Hypothesis Data

Fig. 3. Cambridge



Empirical Study Hypothesis Data

Fig. 4. NYC District 8



Empirical Study Hypothesis Data

Table I. Average cost of winning projects, as a fraction of the budget

	<i>K-approval</i>	<i>knapsack</i>
NYC District 8	0.20	0.12
Cambridge	0.15	0.10

https://pbstanford.org/

Elections

See some of the past PB elections below, or see the [list of cities](#) that have collaborated with us.

South Lake Street Chicago PB Election

You have selected: 1/4 projects.

Submit My Vote

- BLA Gym Renovations**
No more rubber floors and wooden bleachers - the BLA gym will be renovated to include newly painted hoops and floors and new wood bleachers.
Estimated Cost: \$475,000
Location: 200 Transamerica Street, Roxbury
- BOYF Hyde Park Dance Studio Renovation**
A renovated dance studio at the Hyde Park Community Center for children of all ages.
Estimated Cost: \$160,000
Location: 8271 Hyde Park Community Center Hyde Park
- Bike Lane Installation**
After a study, bike lanes will begin to be installed around Charlestown New York, Boston MA housing and Charlestown High.
Estimated Cost: \$100,000
Location: Charlestown

Boston, MA
Approval voting

New York City District 8 Selected \$1,637,000 of \$2,000,000 total budget.

Technology Upgrades
Technology upgrades for Park East High School and Central Park East High School.
Estimated Cost: \$1,000,000

Air Conditioning at Bronx Schools
Installation of air conditioning systems at PS 157A, PS 157B, PS 157C, PS 157D, PS 157E, PS 157F, PS 157G, PS 157H, PS 157I, PS 157J, PS 157K, PS 157L, PS 157M, PS 157N, PS 157O, PS 157P, PS 157Q, PS 157R, PS 157S, PS 157T, PS 157U, PS 157V, PS 157W, PS 157X, PS 157Y, PS 157Z, PS 157AA, PS 157AB, PS 157AC, PS 157AD, PS 157AE, PS 157AF, PS 157AG, PS 157AH, PS 157AI, PS 157AJ, PS 157AK, PS 157AL, PS 157AM, PS 157AN, PS 157AO, PS 157AP, PS 157AQ, PS 157AR, PS 157AS, PS 157AT, PS 157AU, PS 157AV, PS 157AW, PS 157AX, PS 157AY, PS 157AZ, PS 157BA, PS 157BB, PS 157BC, PS 157BD, PS 157BE, PS 157BF, PS 157BG, PS 157BH, PS 157BI, PS 157BJ, PS 157BK, PS 157BL, PS 157BM, PS 157BN, PS 157BO, PS 157BP, PS 157BQ, PS 157BR, PS 157BS, PS 157BT, PS 157BU, PS 157BV, PS 157BW, PS 157BX, PS 157BY, PS 157BZ, PS 157CA, PS 157CB, PS 157CC, PS 157CD, PS 157CE, PS 157CF, PS 157CG, PS 157CH, PS 157CI, PS 157CJ, PS 157CK, PS 157CL, PS 157CM, PS 157CN, PS 157CO, PS 157CP, PS 157CQ, PS 157CR, PS 157CS, PS 157CT, PS 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157ZY, PS 157ZZ

New York City's District 8
Knapsack voting

Chicago 49th Ward

You have selected: 0/4 projects.

Street Resurfacing
Street/Alley Resurfacing and Sidewalk Repairs
What percentage of the total budget should go toward resurfacing streets, sidewalks, and curb repairs?

Map visualization showing selected projects on a street map.

Chicago's 49th Ward
Map visualization

Chicago 49th Ward

You have selected: 4/5 projects.

Vous avez sélectionné les projets suivants. Changez leur classement en faisant glisser les icônes !!

1. Street du Village (\$17,000)
2. Street du passé à la Place 1804 (\$130,000)
3. Installation de plage multifonctionnelle (\$100,000)
4. Cours de français personnalisés (\$7,000)

New York City District 8

Which project gives the best value for money, that is, provides the most benefit to the community per dollar spent?

RS-134 Technology Upgrades
Funds will purchase one laptop cart with printer, six smart boards, and one smart table.
Estimated cost: \$77,000

Humanities and the Arts High School
Technology purchases including two laptop carts and 10 teaching computers.
Estimated cost: \$76,000

Chicago 49th Ward

You have selected: 0/5 projects.

Safety & Environment

Crosswalk Benbow Park
This project's goal is to create a safe connection across a street connecting a park and residential housing in Benbow Park.
Estimated Cost: \$4,000

Pet Waste Basket Benbow Park
Install pet waste bag dispenser and trash receptacle at Benbow Park.
Estimated Cost: \$300

Conclusion

- Value-for-money comparisons is a possible participatory budgeting voting method
- Knapsack voting is strategy-proof, and its outcome is welfare-maximizing
- Knapsack voting is superior to -approval voting
 - But only with the paper's defined situation and assumptions:
 - In participatory budgeting
 - With natural model of user utility (voter satisfaction determined by overlap between preferred budget allocation and final outcome)

Questions?

References

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