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Randomly Selected Representative Committees

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Abstract

When selecting a committee that decides for an entire body of members of a society (a court, legislature, etc.) two main methods are used: random assignment and direct selection (whereby the latter method is made by some authority). It is known that both methods have some flaws (Hasday, 2017). We present a new method that proposes a pool of committees so that by randomly selecting a committee within this pool, all members in the society have equal opportunities of being selected and properties of representativeness and coherence are fulfilled.

Keywords: Representative Committee, Panel Assignment, Institutional Design, Random Assignment, Outlier Panel

JEL classification: D63, D71, K40

1. Introduction

In courts and legislatures around the world, many decisions are made by a committee of members rather than the entire body as a whole. In the judicial setting, for example, the United States federal appellate courts decide many of their cases in panels of three that are selected from the entire appellate circuit (Levy, 2017), and the Supreme Court of Canada, which has nine judges, decides some of its cases by a committee of five or seven judges (Alarie et al., 2015). Committees allow courts and legislatures to be more efficient, i.e., decide more cases or process more legislation, and their small size may enhance collegiality and decision-making (Benda, 1996; Alarie et al., 2015).

Nearly all democratic legislatures, and many nation's highest courts, including Canada, India, South Africa, and the United Kingdom, employ committees (Benda, 1996; Alarie and Green, 2017). In the legislative context, committees play a key role in “screening,

drafting, amending and even, in some cases, approving legislation” (McElroy (2006), p. 6). Legislatures use both standing/permanent committees, which have jurisdiction over proposed legislation, and ad hoc committees, which are formed for a particular purpose and then disbanded once the task is completed (Benda, 1996).

There are two general methods that courts or legislatures use to select their committees: random assignment and direct selection. In random assignment, the members of the committee are randomly selected from the full set of members. For example, the United States federal appellate courts mostly use this selection method to form its three-judge panels (Brown and Lee, 2000; Levy, 2017). Giving each of the members an equal chance to be selected for the committee and preventing any manipulation of the composition of the committee for strategic purposes are some advantages of the random assignment method.

The “fatal flaw” of this method, however, is “outlier” committees, that is, the collective view of the committee does not reflect the collective view of the full set of members (Hasday, 2017). Outlier committees are problematic because they are less likely to contain members who have a diverse range of perspectives, which leads to faulty decisions (Jordan, 2007). Further, per the Condorcet Jury Theorem, if you assume that each member has a better than a 50/50 chance of getting to the correct answer on a given question, then an outlier committee is more likely to lead to the “wrong” answer than a representative committee (Abramowicz, 2000).

The other method that courts or legislatures use to select their committees is direct selection. In direct selection, one or more individuals (hereinafter, the Selector) simply select the members for the particular committee. For example, the chief justice of the Supreme Court of Canada selects the judges for any five- or seven-judge panel (Alarie et al., 2015). Legislatures almost always use a variation of the direct selection method, where party leaders ultimately decide (after getting members’ inputs) which members are assigned to which committees (Damgaard, 1995). The advantage of the direct selection method is that it allows for representative committees if the Selector forms committees that way. For example, McElroy (2006) found that committees on the European Parliament were highly reflective of

the European Parliament as a whole.

However, the “fatal flaw” of this method is strategic manipulation (Hasday, 2017). There is nothing to prevent the Selector from forming a committee that reflects his or her own individual policy views rather than the policy views of the full membership. For instance, Alarie and Green (2017) found evidence that such “gaming” occurred by chief justices of the high court of South Africa from 1950 to 1990. Additionally, since each member does not have an equal chance to be selected for any particular committee, members have an incentive to curry favor with the Selector, which may include voting in the way the Selector desires, in order to be placed on the most desirable committees (Feinstein, 2013).

Thus, a new committee selection procedure is needed that has the benefits of random assignment (equal opportunity, no manipulation) and direct selection (the possibility of representativeness) while avoiding their fatal flaws. An improved mechanism for selecting committees would consist of randomly selecting a committee from a pool of “matching” committees, i.e., committees that are representative of the full set of members. Accordingly, the resulting committee will have the benefits of representativeness. However, by randomly selecting a committee from the pool of matching committees, instead of directly selecting the committee members, the method protects against strategic manipulation on the part of the Selector and eliminates the incentives on the part of the members to align themselves with the Selector in order to get favorable committee assignments. Finally, it should be noted that this new procedure does not need to entirely replace current systems, but can be employed on a targeted basis for situations which require the highest levels of fairness and representativeness, such as death penalty cases at the United States federal appellate courts or ad hoc legislative committees that are formed to investigate a particularly controversial issue.

When describing representativeness of a committee we try to capture the idea that the “position” of the committee is close to that of the whole set of members. But, what do we mean by “position” of a committee? Legislators or judges may be ranked or characterized by ideological criteria on a spectrum (i.e, from more conservative to more liberal). Then, each

member has a “characteristic” and each committee has a “position” given by the average of the characteristics of its members.

In order to eliminate any possibility of strategic manipulation, an objective ranking of the full membership should be sought, such as common space scores (Shor and McCarty, 2011). Ideally, this objective ranking is tailored for the particular topic or case facing the committee. For example, Beim et al. (2018) developed a ranking of United States federal appellate judges in death penalty cases based on prior decisions of the ranked judges in that category of cases. At some point in the future, computers via machine learning may be able to supply the ranking (see generally Chen (2019)). If an objective ranking is not available, a subjective ranking based on the beliefs of one or more of the members of the committee, the litigants, and/or outside experts could be used (Hasday, 2000, 2017; Wijtvliet and Dyevre, 2019).

2. Desirable properties

In order to achieve our objectives, the pool of committees to be formed for random selection should fulfill the following properties:

- *Equal opportunity for the Members*, i.e., each member should have the same chance to serve on any particular committee. This “equal opportunity” principle is particularly important in certain judicial settings, where judges are of “equal status” and therefore have an equal right to be on any panel (see Samaha (2009), p. 71). Additionally, since a judge or legislator has an equal chance to serve on a committee regardless of where they are situated on the ideological spectrum, this principle prevents possible discord among the various ideological camps, as well as strategic positioning by the members.
- *Representativeness*, i.e., the selected committee should have a position relatively close to that of the entire set of members. On a fundamental level, this principle is justified on an agent-principal view of committees where the committee is intended to be the faithful servant of the membership as a whole (Ginsburg and Falk, 1991). In the

judicial setting, this property will enhance the consistency, predictability, and fairness of the decision-making (i.e., like cases will be decided in a like manner), which are the cornerstone values of any legal system (Hasday, 2000). Finally, this “representative” property can be justified based on the Condorcet Jury Theorem, as discussed above.

- *Coherence* in the selection, i.e., if a committee is in the pool of committees, a more representative committee should also be in the pool of committees. This principle will ensure that the pool of committees has the lowest expected difference in position from that of the entire set of members, given the constraint that each member has an equal opportunity to serve on the particular committee.

3. A formal model

We assume throughout that $N = \{1, 2, \dots, n\}$ with $n > 2$ is the set of members that can be part of a committee of size $s < n$. Each member i has a characteristic that can be represented by a positive real number $\alpha_i \in \mathbb{R}_+$; thus, $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_n)$ is the characteristic vector for the members. We suppose that we are not in a trivial case and not all the characteristics are equal.

Let C be the set of all the possible committees of size s with members in N . The set C contains

$$m = \binom{n}{s} = \frac{n!}{(n-s)!s!}$$

committees. Each committee $c \in C$ can be denoted by a vector in $\{0, 1\}^n$, $c = (c_1, c_2, \dots, c_n)$ such that s , and only s , entries of the vector have the value 1, representing which members belong to the committee. We write that member $i \in c$, if $c_i = 1$ and $i \notin c$, if $c_i = 0$.

We denote by $\Lambda(N) = \sum_{i \in N} \frac{\alpha_i}{n} = \frac{\alpha \mathbf{e}}{n}$ the average position of the whole set of members. We refer to $\Lambda(N)$ as the position of N . In the same way, $\Lambda(c) = \sum_{i \in c} \frac{\alpha_i}{s} = \frac{\alpha c}{s}$ represents the average position of committee $c \in C$.¹

¹We denote by $\mathbf{e}$ the vector in $\mathbb{R}^n$ with all entries equal to 1, $\mathbf{e} = (1, 1, \dots, 1)$. Given two vectors in $\mathbb{R}^n$,

We denote by $d(c, N) = |\Lambda(c) - \Lambda(N)|$ the distance between the average positions of the entire set of members and that of the committee c . We call this value the distance of the committee c to N . The closer the position of a committee is to $\Lambda(N)$ (the smaller the distance of c to N) the more representative of the whole set of members N the committee is.

The feasible pools of committees are elements in the power set $\mathcal{P}(C)$ (the set with all the subsets of C). Note that $\mathcal{P}(C)$ is in general a very large set, even for a small number of members (for instance, with 6 members and committees of size 3 we have more than one million possible pools of committees). For each pool $P \in \mathcal{P}(C)$, consider the vector $K(P) = \sum_{c \in P} c$. Then, $K_i(P)$ represents the times that member i appears in the committees within P . Note that, in order to guarantee equal opportunities for all members, we are interested in pools of committees for which all the entries of vector $K(P)$ are equal.

With the aim of selecting a committee representative of the whole set of members N in a “fair” way, we propose to choose it randomly from a “particular” pool of committees. Then, the main question is: what should be in this “particular” pool of committees so that the required properties are fulfilled?

If $P \in \mathcal{P}(C)$ is the pool of committees that we use to choose randomly within, let us formalize the properties it should fulfill. We say that P provides:

- **Equal opportunities for all Members (EOM):** All members have the same probability of being in the selected committee. This fact is true when all members appear the same number of times in P , that is

$$K(P) = r\mathbf{e}, \text{ where } r \in \mathbb{N}$$

- **ε -Representativeness (ε -R):** P guarantees that the selected committee has a position relatively close (the distance should be smaller than ε) to that of the whole set of members.

$v = (v_1, \dots, v_n)$ and $w = (w_1, \dots, w_n)$, vw denotes the classical scalar product, $vw = v_1w_1 + \dots + v_nw_n$. Thus, for instance, $\alpha\mathbf{e} = \sum_{i=1}^n \alpha_i$.

For any $c \in P$, $d(c, N) \leq \varepsilon$

- **Coherence in representativeness (CR):** If a committee is in P , a more representative committee should be in P too.

If $d(c', N) < d(c, N)$ and $c \in P$, then $c' \in P$

From these properties, EOM is an essential requirement, since it guarantees equal opportunities for all members. Coherence tries to avoid not considering committees that have a position closer to the position of N than other committees being selected (for instance, for strategic purposes). Finally, Representativeness is also a desirable property, although, obviously, we cannot obtain a pool satisfying ε -R for any $\varepsilon \geq 0$ because there could even be no committees at a distance smaller than ε . Then, our goal is to obtain a pool satisfying EOM, CR and ε -R for an ε as small as possible.

4. The optimal pool of committees

Consider the following set H of pools of committees, such that each pool P in H satisfies Equal Opportunities of Members and Coherence in Representativeness:

$$H = \{P \in \mathcal{P}(C) : K(P) = r\mathbf{e}, r \in \mathbb{N} \text{ and if } d(c', N) < d(c, N), c \in P, \text{ then } c' \in P\}$$

Obviously, this set is non-empty, $H \neq \emptyset$, because $\{C\} \in H$. For each $P \in H$, $d(P) = \max_{c \in P} d(c, N)$ is the distance to N of the committee in P with the farthest position to N . Let us select the elements in H that minimize the previous distance:

$$H^* = \left\{ \arg \left\{ \min_{P \in H} d(P) \right\} \right\}$$

We denote by $d^* = \min_{P \in H} d(P)$.

For any $x \in \mathbb{R}_+$, $pr(P, x)$ represents the probability that a committee in P is exactly at a distance x to N . Then,

$$pr(P, x) = \frac{|c \in P : d(c, N) = x|}{|P|}$$

Definition 1. A pool of committees $P^0 \in \mathcal{P}(C)$ is said to be **optimal** if:

1. $P^0 \in H^*$
2. If $P \in H^*, P \neq P^0$ then $pr(P, d^*) > pr(P^0, d^*)$

In general, there may be several optimal pools of committees. We denote by $O(C)$ the set of all optimal pools of committees. Observe that condition 2 of optimality means that if we have more than one pool in H^* we will use the ones in which the probability of selecting a committee at the greatest distance from N (the worst committees) is as small as possible.

4.1. *Properties of the optimal pool*

Being H a finite set, $\min_{P \in H} d(P)$ always exists and then H^* is a non-empty set. So, $O(C)$ will contain pools P^0 in H^* such that $pr(P^0, d^*) \leq pr(P, d^*)$ for any $P \in H^*$. As $O(C) \subseteq H^* \subseteq H$, each $P^0 \in O(C)$ is obviously a pool providing EOM and CR. Furthermore, for each $P^0 \in O(C)$ and each $c \in P^0$, $d(c, N) \leq d^*$, so P^0 provides d^* -representativeness.

If there is some pool $P \in \mathcal{P}(C)$ not contained in $O(C)$, $P \notin O(C)$, providing EOM and CR, then it should be in H and $d(P) \geq d(P^0) = d^*$, for all $P^0 \in O(C)$. Therefore, if P provides ε -representativeness, $\varepsilon \geq d^*$. In conclusion, each P^0 in $O(C)$ is a pool providing EOM, CR and ε -representativeness for ε as small as possible.

Although the previous definition gives us an easy way of studying the existence and properties of this family of optimal pools, the computation of $O(C)$ is not an easy task by using the definition. The problem lies in the large number of sets of committees in $\mathcal{P}(C)$. Next, we present an algorithm to obtain pools in $O(C)$ in an easy way, without having to use the sets in $\mathcal{P}(C)$.

Keep in mind that, in order for a pool of committees to provide EOM, it is not possible for it to have any number of committees. In particular, the number of committees in the pool

(k) multiplied by the number of members in each committee (s) must be a multiple of the total number of members (n). That is, if $P \in \mathcal{P}(C)$ provides EOM and it has k committees ($|P| = k$) then, $ks = rn$ with $r \in \mathbb{N}$. Thus, $k = \frac{rn}{s} \leq m$ and the possibilities for the number of committees in P are the integers values in $\left\{ \frac{n}{s}, \frac{2n}{s}, \frac{3n}{s}, \dots, m \right\}$.

4.2. *An algorithm to obtain an optimal pool*

By means of the following process we can compute pools in $O(C)$. We divide the algorithm in two parts. And the second part in two cases (the second one, the most general, is explained in the Appendix).

Algorithm:

1. **Ordering committees**

1.1 Compute the position of N : $\Lambda(N) = \sum_{i=1}^n \frac{\alpha_i}{n}$

1.2 Obtain the set of all possible committees of size s , C

Note that there are exactly $m = \binom{n}{s} = \frac{n!}{(n-s)! s!}$ committees of size s

1.3 For each committee $c \in C$, compute its position: $\Lambda(c) = \sum_{i \in c} \frac{\alpha_i}{s}$

1.4 For each committee, compute the distance to N : $d(c, N) = |\Lambda(N) - \Lambda(c)|$

1.5 Order the committees from low to high according to its distance to N (ties can be ordered as desired). Then, write C in that order (from nearest to farthest):

$$C = \{c^1, c^2, \dots, c^m\}$$

After these steps, we obtain an ordered list of the m committees:

A set of m_1 committees at a distance d_1 , denoted by M_1

A set of m_2 committees at a distance d_2 , denoted by M_2

...

A set of m_t committees at a distance d_t , denoted by M_t

These sets fulfill:

$$i < j \Rightarrow d_i < d_j \text{ and } m_1 + m_2 + \dots + m_t = m$$

2. Selecting a pool of committees

Now, we are going to select committees beginning from the nearest to N (the one with lowest distance $d(c, N)$). Since the first objective is that all members must appear the same number of times, we only need to check pools of committees that contain $k \in \mathbb{N}$ committees, where k is chosen such that ks is a multiple of n .

4.2.1. *Selecting a pool of committees case 1: no ties* ($\forall i, m_i = 1$)

2.1 Find the first integer number $k \in \mathbb{N}$ such that ks is a multiple of n

2.2 Set $p = 1$

2.3 Compute the sum of the first $r = pk$ vectors (committees):

$$K(1 \text{ to } r) = \sum_{j=1}^r c^j = c^1 + c^2 + \dots + c^r$$

2.4 Check if all components in $K(1 \text{ to } r)$ are identical. That means that all members appear the same number of times.

- If the answer is “yes,” we have the optimal pool.

$$P^* = \{c^1, c^2, \dots, c^r\}$$

- If the answer is “no,” then set $p = p + 1$ and return to step 2.3.

Theorem 1. *The set of committees obtained with the previous procedure is an optimal pool in $O(C)$; that is, P^* is a pool providing EOM, CR and ε -R for ε as small as possible.*

Proof. Let P^* be the pool obtained with the previous algorithm. And let $c^r \in P^*$ be the last committee selected and $d_r = d(c^r, N)$ its distance to N . Obviously, by construction, P^* provides EOM and CR and ε -R for an ε as small as possible, in this case $\varepsilon = d_r$. Suppose that P^* is not an optimal pool of committees, $P^* \notin O(C)$. Then there is a pool $P^0 \in O(C)$ and a committee $c^j \in P^0$ such that $c^j \notin P^*$. In that case, for any $d^* \geq d(c^j, N) > d(c^r, N) = d_r$, a contradiction with the definition of optimal pool. So, P^* is an optimal pool. ■

Remark 1. *The previous result is always true, independently if there are ties or not. Observe that when all the committees have a different distance to N (no ties), only one pool can be obtained by applying the previous algorithm, so the uniqueness of an optimal pool P^0 is deduced. This uniqueness is not guaranteed in the general case shown in the Appendix, where the existence of several optimal pools is possible.*

5. An example

Example 1. *Consider the set of members:*

$$N = \{\text{Smith, Jones, Williams, Brown, Wilson, Taylor, Johnson}\}$$

We want to obtain a pool of 3-member committees from which we will select randomly one of them in order to represent the whole set N . Then $n = 7$, and $s = 3$. In this case, there are 35 possible committees and more than 34 billion possible pools of committees. Table 1 shows the characteristic of each member.

Table 1: Members' Characteristics in Example 1

MEMBER	Smith	Jones	Williams	Brown	Wilson	Taylor	Johnson
LABEL	A	B	C	D	E	F	G
CHARACTERISTIC	3.2	3.9	5.1	7.9	10	13	14.1

Then, the position (the average characteristic) of the group is $\Lambda(N) = 8.17$. We compute the position of each 3-committee, its difference from the group position, and order them from nearest to farthest positions. Table 2 shows the result.

Table 2: Committees Ordered by Their Distance to N in Example 1

ORDER	COMMITTEE	VECTOR c	POSITION $\Lambda(c)$	DISTANCE $d(c, N)$
1	BDF	(0, 1, 0, 1, 0, 1, 0)	8.27	0.10
2	ADF	(1, 0, 0, 1, 0, 1, 0)	8.03	0.14
3	ADG	(1, 0, 0, 1, 0, 0, 1)	8.40	0.23
4	BDG	(0, 1, 0, 1, 0, 0, 1)	8.63	0.46
5	BCG	(0, 1, 1, 0, 0, 0, 1)	7.70	0.47
6	CDF	(0, 0, 1, 1, 0, 1, 0)	8.67	0.49
7	CDE	(0, 0, 1, 1, 1, 0, 0)	7.67	0.50
$K(1 - 7)$		(2, 3, 3, 6, 1, 3, 3)		
8	AEF	(1, 0, 0, 0, 1, 1, 0)	8.73	0.56
9	ACG	(1, 0, 1, 0, 0, 0, 1)	7.47	0.70
10	BEF	(0, 1, 0, 0, 1, 1, 0)	8.97	0.80
11	BCF	(0, 1, 1, 0, 0, 1, 0)	7.33	0.84
12	CDG	(0, 0, 1, 1, 0, 0, 1)	9.03	0.86
13	BDE	(0, 1, 0, 1, 1, 0, 0)	7.27	0.90
14	AEG	(1, 0, 0, 0, 1, 0, 1)	9.10	0.93
$K(1 - 14)$		(5, 6, 6, 8, 5, 6, 6)		
15	ACF	(1, 0, 1, 0, 0, 1, 0)	7.10	1.07
16	ABG	(1, 1, 0, 0, 0, 0, 1)	7.07	1.10
17	ADE	(1, 0, 0, 1, 1, 0, 0)	7.03	1.14
18	BEG	(0, 1, 0, 0, 1, 0, 1)	9.33	1.16
19	CEF	(0, 0, 1, 0, 1, 1, 0)	9.37	1.20
20	ABF	(1, 1, 0, 0, 0, 1, 0)	6.70	1.47
21	CEG	(0, 0, 1, 0, 1, 0, 1)	9.73	1.56
$K(1 - 21)$		(9, 9, 9, 9, 9, 9, 9)		
22	BCE	(0, 1, 1, 0, 1, 0, 0)	6.33	1.84
23	AFG	(1, 0, 0, 0, 0, 1, 1)	10.10	1.93
24	ACE	(1, 0, 1, 0, 1, 0, 0)	6.10	2.07
25	DEF	(0, 0, 0, 1, 1, 1, 0)	10.30	2.13
26	BFG	(0, 1, 0, 0, 0, 1, 1)	10.33	2.16
27	ABE	(1, 1, 0, 0, 1, 0, 0)	5.70	2.47
28	DEG	(0, 0, 0, 1, 1, 0, 1)	10.67	2.50
29	BCD	(0, 1, 1, 1, 0, 0, 0)	5.63	2.54
30	CFG	(0, 0, 1, 0, 0, 1, 1)	10.73	2.56
31	ACD	(1, 0, 1, 1, 0, 0, 0)	5.40	2.77
32	ABD	(1, 1, 0, 1, 0, 0, 0)	5.00	3.17
33	DFG	(0, 0, 0, 1, 0, 1, 1)	11.67	3.50
34	ABC	(1, 1, 1, 0, 0, 0, 0)	4.07	4.10
35	EFG	(0, 0, 0, 0, 1, 1, 1)	12.37	4.20

After the first 7 committees, the members appearances are:

MEMBER	Smith	Jones	Williams	Brown	Wilson	Taylor	Johnson
APPEARANCES	2	3	3	6	1	3	3

so this pool is not valid. After checking the first 14 committees, the members appearances are:

MEMBER	Smith	Jones	Williams	Brown	Wilson	Taylor	Johnson
APPEARANCES	5	6	6	8	5	6	6

so this pool is also not valid. After checking the first 21 committees, all the members appear 9 times, and this is the optimal pool. This pool has 21 committees and when we randomly choose a committee within this pool, all members have the same probability to be in the selected committee. Moreover, the position of the committee differs, in the worst case, by 19% with respect to the entire group position (by only 1% in the best case). The expected difference in position is 9.7%. This is the best that we can do if we want all members to have equal opportunities.

If the 3-member committee is randomly selected (that is, we consider the pool with all (35) possible 3-member committees), the expected difference with respect to the entire group position is 19.1%, nearly twice the difference of our proposal. In this case, the worst possible case differs by 51.34%. Note that the worst committee in our proposed pool nearly equals the median difference in the random case.

Sometimes it is not possible to find a set of committees different from the one formed by all the committees guaranteeing equal opportunities for all members. This would be the case, for example, of the situation with 3 members and 2-member committees, regardless of their characteristics.

Appendix

Selecting a pool of committees case 2: the general case

If there are some ties in the distance from the position of different committees, the process is a bit more elaborate, although it shares the same idea. Remember how we have ordered the committees after the first part of the process.

Find the first natural number $k \in \mathbb{N}$ such that ks is a multiple of n . We distinguish two cases:

1. $m_1 < k$

1.1 Set $p = 1$

1.2 Let $r = pk$

1.3 If $m_1 + m_2 + \dots + m_{t_p} < r \leq m_1 + m_2 + \dots + m_{t_p} + m_{t_p+1}$

Sum all vectors in $M_1 \cup M_2 \cup \dots \cup M_{t_p}$ and add subsets of vectors in M_{t_p+1} such that the total number of vectors (committees) is r .

1.4 Check if all components in any of the above sums have all components identical.

If so, this is an optimal pool.

If this is not possible, set $p = p + 1$ and return to step 1.2.

2. $m_1 \geq k$

2.1 Let $q^* \in \mathbb{N}$ such that $q^*k \leq m_1 < (q^* + 1)k$

2.2 Check if there is a subset of M_1 with exactly q^*k vectors such that the sum has all components identical. In this case, this is an optimal pool. If it is not possible, try with $(q^* - 1)k$ vectors, and so on with all the positive integers lower than q^* . If it is not possible to find a pool in M_1 satisfying equal opportunities for all members (EOM), then go to the following step.

2.3 Set $p = q^*$

2.4 Let $r = pk$

2.5 If $m_1 + m_2 + \dots + m_{t_p} < r \leq m_1 + m_2 + \dots + m_{t_p} + m_{t_p+1}$

Sum all vectors in $M_1 \cup M_2 \cup \dots \cup M_{t_p}$ and add subsets of vectors in M_{t_p+1} such that the total number of vectors (committees) is r .

2.6 Check if all components in any of the above sums has all components identical. If so, this is the optimal pool.

If this is not possible, set $p = p + 1$ and return to step 2.4.

We illustrate the above algorithm with a slight modification of our Example 1.

Example 2. Consider the set of members:

$$N = \{Smith, Jones, Williams, Brown, Wilson, Taylor, Johnson\}$$

As before, we want to obtain a pool of 3-member committees, from which we will select randomly one of them in order to represent the whole set N , but the characteristics have changed. Table 3 shows the new characteristic of each member.

Table 3: Members' Characteristics in Example 2

MEMBER	Smith	Jones	Williams	Brown	Wilson	Taylor	Johnson
LABEL	A	B	C	D	E	F	G
CHARACTERISTIC	3	4	5	8	10	13	14

Then, the position (the average characteristic) of the group is now $\Lambda(N) = 8.14$. We compute the position of each 3-committee, its difference from the group position, and order them from nearest to farthest positions. Table 4 shows the result. As can be observed, unlike Example 1, there are several ties in the distance of some committees to the entire group and we cannot apply the simplified algorithm.

We observe that committees that occupy order 6, 7 and 8 have the same distance to the entire group. As we need to check for a pool with exactly seven committees, we need to check $K(P)$ for the following cases:

- $P^1 = \{c^1, c^2, c^3, c^4, c^5, c^6, c^7\}$ $K(P^1) = (3, 3, 2, 5, 2, 3, 3)$
- $P^2 = \{c^1, c^2, c^3, c^4, c^5, c^6, c^8\}$ $K(P^2) = (3, 3, 2, 5, 2, 4, 2)$
- $P^3 = \{c^1, c^2, c^3, c^4, c^5, c^7, c^8\}$ $K(P^3) = (3, 3, 2, 6, 1, 3, 3)$

So, in any case we obtain a not valid pool.

Table 4: Committees Ordered by Their Distance to N in Example 2

ORDER	COMMITTEE	VECTOR c	POSITION $\Lambda(c)$	DISTANCE $d(c, N)$
1	ADF	(1, 0, 0, 1, 0, 1, 0)	8	0.14
2	BDF	(0, 1, 0, 1, 0, 1, 0)	8.33	0.19
3	ADG	(1, 0, 0, 1, 0, 0, 1)	8.33	0.19
4	CDE	(0, 0, 1, 1, 1, 0, 0)	7.67	0.48
5	BCG	(0, 1, 1, 0, 0, 0, 1)	7.60	0.48
6	CDF	(0, 0, 1, 1, 0, 1, 0)	8.67	0.52
7	BDG	(0, 1, 0, 1, 0, 0, 1)	8.67	0.52
8	AEF	(1, 0, 0, 0, 1, 1, 0)	8.67	0.52
9	BDE	(0, 1, 0, 1, 1, 0, 0)	7.33	0.81
10	BCF	(0, 1, 1, 0, 0, 1, 0)	7.33	0.81
11	ACG	(1, 0, 1, 0, 0, 0, 1)	7.33	0.81
12	CDG	(0, 0, 1, 1, 0, 0, 1)	9	0.86
13	BEF	(0, 1, 0, 0, 1, 1, 0)	9	0.86
14	AEG	(1, 0, 0, 0, 1, 0, 1)	9	0.86
15	ADE	(1, 0, 0, 1, 1, 0, 0)	7	1.14
16	ACF	(1, 0, 1, 0, 0, 1, 0)	7	1.14
17	ABG	(1, 1, 0, 0, 0, 0, 1)	7	1.14
18	BEG	(0, 1, 0, 0, 1, 0, 1)	9.33	1.19
19	CEF	(0, 0, 1, 0, 1, 1, 0)	9.33	1.19
20	ABF	(1, 1, 0, 0, 0, 1, 0)	6.67	1.48
21	CEG	(0, 0, 1, 0, 1, 0, 1)	9.67	1.52
22	BCE	(0, 1, 1, 0, 1, 0, 0)	6.33	1.81
23	AFG	(1, 0, 0, 0, 0, 1, 1)	10	1.86
24	ACE	(1, 0, 1, 0, 1, 0, 0)	6	2.14
25	DEF	(0, 0, 0, 1, 1, 1, 0)	10.33	2.19
26	BFG	(0, 1, 0, 0, 0, 1, 1)	10.33	2.19
27	BCD	(0, 1, 1, 1, 0, 0, 0)	5.67	2.48
28	ABE	(1, 1, 0, 0, 1, 0, 0)	5.67	2.48
29	DEG	(0, 0, 0, 1, 1, 0, 1)	10.67	2.52
30	CFG	(0, 0, 1, 0, 0, 1, 1)	10.67	2.52
31	ACD	(1, 0, 1, 1, 0, 0, 0)	5.33	2.81
32	ABD	(1, 1, 0, 1, 0, 0, 0)	5.00	3.14
33	DFG	(0, 0, 0, 1, 0, 1, 1)	11.67	3.52
34	ABC	(1, 1, 1, 0, 0, 0, 0)	4	4.14
35	EFG	(0, 0, 0, 0, 1, 1, 1)	12.33	4.19

After checking the first 14 committees, the members appearances are:

MEMBER	Smith	Jones	Williams	Brown	Wilson	Taylor	Johnson
APPEARANCES	5	6	6	8	5	6	6

so this pool is also not valid.

After checking the first 21 committees, all the members appear 9 times, and this is the optimal pool. This pool has 21 committees and when we randomly choose a committee within this pool, all members have the same probability to be in the selected committee. Moreover, the position of the committee differs, in the worst case, by 18.7% with respect to the entire group position (by only 2.3% in the best case). The expected difference in position is 9.8%. This is the best that we can do if we want all members to have equal opportunities.

If the 3-member committee is randomly selected (that is, we consider the pool with all (35) possible 3-member committees), the expected difference with respect to the entire group position is 19.2%, nearly twice the difference of our proposal. In this case, the worst possible case differs by 51.5%. Note that the worst committee in our proposed pool is better than the average in the random case.

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