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An artificial system for selecting the optimal surgical team

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Abstract

We introduce an intelligent system to optimize a team composition based on the team's historical outcomes and apply this system to compose a surgical team. The system relies on a record of the procedures performed in the past. The optimal team composition is the one with the lowest probability of unfavorable outcome. We use the theory of probability and the inclusion exclusion principle to model the probability of team outcome for a given composition. A probability value is assigned to each person of database and the probability of a team composition is calculated from them. The model allows to determine the probability of all possible team compositions even if there is no recoded procedure for some team compositions. From an analytical perspective, assembling an optimal team is equivalent to minimizing the overlap of team members who have a recurring tendency to be involved with procedures of unfavorable results. A conceptual example shows the accuracy of the proposed system on obtaining the optimal team.

I. Introduction

It is a common understanding that the outcome of a team operation depends on the team members and their composition. As an example, the outcome of a game depends on the players elected for each position and how well they can play with each other. Surgery is also a team work whose outcome depends on the team composition. However in practice, selection of a team composition for a surgery is usually based on the availabilities and schedules of the personnel rather than the expected outcome of each composition.

There are several studies that support the effect of the team composition on the outcome of surgery. According to the National Surgical Quality Improvement Program (NSQIP) criteria, surgical teams are held accountable for many post-operative diagnoses up to 30 days after a procedure [1]. Wiegmann et. al [2] assert that a strong linkage exists between teamwork-related disruptions and surgical errors ($r=0.67$, $p < 0.001$). Using a Behavioral Marker Risk Index (BMRI), Mazzocco et. al [3] demonstrated that a noticeable difference existed between well and poorly functioning intraoperative teams in the percentage of cases with surgical complications due to information sharing, inquiry and vigilance errors. Rydenfaelt et. al [4] proposed that if a hospital could "give the team members a common activity history" then the rate of surgical complications might diminish.

The operating room (OR) is a complex socio-technical system with a predisposition for error. Studies of surgical team composition and its impact on performance are sporadic. As

attention to surgical quality has shifted from the individual to the team. The methods and data are needed to find the optimal team composition and improve communication and coordination in the OR.

This paper presents an intelligent system developed based on the theory of probability and the inclusion exclusion principle to compose an optimal team [5]. This system can be applied to any team work where the past records of operations are available for a sufficient number of team compositions and operations. These records should include the elected members for the operations and sufficient data to evaluate the outcomes. The evaluation data could be simple binary results of "win" or "lost" or a collection of operation states that show whether the operations were successful or not. We first obtain the probability of unfavorable outcome for all team compositions that have operation records. A probability value is then assigned to each person of the database based on his/her record on all participated team compositions. A model is introduced to calculate the probability for any team composition based on the probability values for the members of the team. The optimal team is selected by finding the team which has the minimum probability.

This paper is arranged as follows. Section II presents a model to calculate the probability of unfavorable outcome of a given team composition. Section III explains a method to identify the probability values of the members of a team from failure rates of past procedures. A conceptual example for probability identifications is presented in Section IV. Conclusions appears in Section V.

II. Probability Model of Outcome

The outcome of a team work is considered as a discrete binary output such as "lost or win", "pass or fail" or "satisfactory or unsatisfactory". A binary conclusion is not directly applicable to a surgical procedure. Therefore, we first evaluate the outcome of a surgery by a continuous variable and then map that variable to a binary outcome. If the continuous variable is less than the threshold, the outcome is unsatisfactory and if not, the outcome is satisfactory.

As an example the duration of a surgical procedure can be used as a measure to categorize surgical procedures into satisfactory or unsatisfactory. Even a more comprehensive time measurement such as the combination of the durations of the surgical operation, hospital stay and full recovery can be used. We define T_k as k th team of all possible team compositions. Each T_k is comprised of s number of positions which are filled by members m_{i_k}

$$T_k = \bigcup_{i=1}^s m_{i_k} \quad (1)$$

where m_{i_k} is a member at position i of the team k . We evaluate a team T_k with a number P , defined as the number of unsatisfactory or failed procedures of the team (F_k) divided by the total number of procedures of the team (R_k);

$$P(T_k) = F_k/R_k \quad (2)$$

For a very large R_k , $P(T_k)$ is the probability of the team T_k having an unsatisfactory procedure.

Calculating $P(T_k)$ requires a large number of procedure outcomes for the team k . Consider a team that has S positions which are selected from N possible team members. The number of

team compositions are $\binom{N}{S}$. Many team compositions have no or a few procedures. This makes calculating P for these teams inaccurate. Therefore, we propose the probability model for independent events to calculate $P(T_k)$.

$$P(T_k) = \sum_{j=1}^s (-1)^{j-1} \sum_{I_j} \prod_{i \in I_j} P(m_{i_k}) \quad (3)$$

where $P(m_{i_k})$ is the probability of causing a complication for a member that is at position i in team k . The model allows to use available results of team compositions with significant records to calculate P for the team compositions that do not have significant number of results.

This equation calculates the occurrence probability of the union of a set of independent events. We assume that the unsatisfactory outcome for a team T_k is due to occurrence of a fault (a collection of actions that leads to an unsatisfactory procedure) by one of the team members. Also we assume that faults are independent events. This does not mean that members do not affect each other; in fact the value of $P(m_{i_k})$ for each member can depend on the co-workers' performances as well. The above equation only assumes whenever a fault happens, the occurrence is not dependent on previous or future faults. $P(m_{i_k})$ can depend on team composition however for this paper we consider a constant $P(m_{i_k})$ for each member.

III. Identifying Member Probabilities

To use Eq 3, the probability values of all members are necessary. The team results do not directly determine P of members. In this section we developed a method to identify P values of the members from team results.

Assume A is a team member that has done many procedures with other members and his results are available. We collect all of the results and calculate the probability of unfavourable or unsatisfactory results for all the teams consisting A , defined as $P(A_{teams})$. We divide the number of unsatisfactory procedures of all teams consisting A , F_A to total procedures performed by those teams, R_A to obtain $P(A_{teams}) = F_A/R_A$

Using Eq 3, the same value is obtained by

$$\begin{aligned}
P(A_{teams}) &= \frac{1}{|K_A|} \sum_{k \in K_A} \{P(T^k)\} \\
&= \frac{1}{|K_A|} \sum_k P\left(A \cup_{i \in I_{s-i_A}} m_{i_k}\right) \\
&= \frac{1}{|K_A|} \sum_k \left(P(A) + P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right) \right. \\
&\quad \left. - P(A) P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right) \right) \\
&= P(A) \left(1 - \frac{1}{|K_A|} \sum_k P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right) \right) \\
&\quad + \frac{1}{|K_A|} \sum_k P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right), \tag{4}
\end{aligned}$$

where K_A is the set of teams that A is a member of them, $|K_A|$ is the size of the set, i_A is the index belonging to A in the team, and $P(A)$ is the complication rate of a member named A. Rearranging (4), we obtain $P(A)$ as

$$P(A) = \frac{P(A_{teams}) - \frac{1}{|K_A|} \sum_k P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right)}{1 - \frac{1}{|K_A|} \sum_k P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right)} \tag{5}$$

The member A can be replaced by other members that can perform the same role. We define M_A as a set of members (including A) that can perform the role of A and K_M as the set of teams that include any of the members of M_A performing task of member A. Assuming all of these members have the same index in their team denoted by i_A , we can calculate the average complication probability for the database:

$$\begin{aligned}
P_{av} &= P(M_A) + \frac{1}{|K_M|} \sum_{k \in K_M} P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right) \\
&\quad - P(M_A) \frac{1}{|K_M|} \sum_{k \in K_M} P\left(\bigcup_{i \in I_{s-i_A}} m_{i_k}\right) \tag{6}
\end{aligned}$$

Where $P(M_A)$ is the complication probability by any member that performs the task of A. Note that any role other than role of A can also be substituted in the above formula to give us a similar formula concerning a different task. This concludes:

$$\frac{1}{|K_M|} \sum_{k \in K_M} P \left(\bigcup_{i \in I_{s-i_A}} m_{i_k} \right) = \frac{P_{av} - P(M_A)}{1 - P(M_A)} \quad (7)$$

Note that K_M is larger than K_A , and if we exclude M_A from the teams of the two sets, the remainder of the teams in K_M are repetitions of the remainder of the teams in K_A by $|K_M|/|K_A|$ times. Therefore:

$$\sum_{k \in K_M} P \left(\bigcup_{i \in I_{s-i_A}} m_{i_k} \right) = \frac{|K_M|}{|K_A|} \sum_{k \in K_A} P \left(\bigcup_{i \in I_{s-i_A}} m_{i_k} \right) \quad (8)$$

OR,

$$\frac{1}{|K_M|} \sum_{k \in K_M} P \left(\bigcup_{i \in I_{s-i_A}} m_{i_k} \right) = \frac{1}{|K_A|} \sum_{k \in K_A} P \left(\bigcup_{i \in I_{s-i_A}} m_{i_k} \right) \quad (9)$$

Substituting (7) into (5) concludes:

$$\begin{aligned} P(A) &= 1 - \frac{1 - P(A_{teams})}{1 - \frac{P_{av} - P(M_A)}{1 - P(M_A)}} \\ &= 1 - \frac{(1 - P(A_{teams}))(1 - P(M_A))}{1 - P_{av}} \end{aligned} \quad (10)$$

This indicates that $P(A)$ can be obtained from three average probability values: P_{av} , $P(A_{teams})$, and $P(M_A)$. It should be mentioned that (10) can be used for any other member performing the same role or a different role, by substituting the corresponding role in the formula. The model (10) shows that each member of the set M_A is linearly influenced by two factors that depend on $P(M_A)$ and P_{av} .

IV. Optimal Team

The optimal team is the one with minimum probability. It can be seen that the optimizer is not sensitive to the value of $P(M_A)$ when choosing a member who can perform the task of A, since $P(M_A)$ only provides a constant term in the probability values of all members in M_A .

We can estimate $P(M_A) = \frac{P_{av}}{m}$ when the complication rates for M_A is not available. This is a rough estimate obtained by assuming that the team complication rate is uniformly divided among all team members.

V. Conceptual Example

Here, we evaluate the identification method of the last section for a simulated surgical environment. It should be mentioned that internal data of the simulated surgical environment is not directly available to the intelligent system or the probability model. Only inputs and outputs of the simulated environment are available.

A. Simulated environment

For the sake of clarity and space, we consider a database that consists of three surgeons, three nurses, and three assistants. We use a simulator that for each procedure picks up a team composition and then considers a task for each team member. Each member task can cause the procedure to fail. The chance of failure for each member task is shown in the table I. Note that this is an internal data not available to our estimator. The procedure fails if one of member task fails. The simulator generates 1000 procedures for each team in this example. Table II shows the number of unfavorable procedures for the teams compositions as a result of our simulation. The data of Table II will be available to the estimator. In this example, we consider a large number of procedures for each team to evaluate our method and the estimator in the best conditions. However, the estimator does not require the same large number of procedures for all team in general. Table III shows the probability of unfavorable (failed) procedures for each team composition derived from table II.

After gathering procedure results, we need to extract $P(A_{teams})$ and P_{av} . $P(A_{teams})$ for each member is calculated from averaging over the complication probabilities of all teams that include A. For example if we want to calculate $P(A_{teams})$ for surgeon 1, we need to average out the probabilities of teams 111, 112, 113, 121, 122, 123, 131, 132, and 133. Table V-A shows $P(A_{teams})$ for all members. P_{av} is the average complication probability of all teams.

Based on the model in equation (10) the only component which is not available to the optimizer is $P(M_A)$, the roles complication probabilities. As explained in the previous section the value of $P(M_A)$ affects all of the individual complication probabilities equally and inaccurate value of this probability does not change the outcome of the optimizer. Therefore we can assume any number for this probability such as 1/3. Now we can estimate the members' complication probabilities.

Table IV shows the estimated members' complication probabilities. Comparing the table III and table IV shows that the complications are different due to inaccurate selection of $P(M_A)$. However components of the rows of both tables have the same locations if both tables (only rows) are sorted from the largest to the smallest. So any team optimization based on any of these tables will have the same results. For example team 211 has the minimum unfavorable outcome rate of 0.14 amongst all of the teams based on table II and III. The same team has the minimum unfavorable outcome rate based on table VI. The unfavorable outcome value is different from the actual value, but the model is focused on finding the best team, not its actual unfavorable outcome rate.

We repeated the above method for finding the optimal team for more realistic situations where there are team compositions that have not done any surgery. Since the number of

procedures for some team compositions are zero, the rate of those compositions cannot be directly derived from the number of failed procedures over their total procedures (which is zero). The presented estimator however was able to calculate a probability rate for any team with zero procedure and calculate its performance ranking.

VI. Conclusions

We developed a system that can recommend the optimal team composition for a surgery only based on the recorded unfavorable outcome rates of surgical teams. This system does not require an expert to find which member of surgical team is responsible for most unfavorable outcomes and who causes the least complications. The system itself can judge the performance of the members of a surgical team based on only recorded data. The method of optimizing team composition can be also applied to other applications.

References

- [1]. Khuri S, Daley J, Henderson W, Hur K, Demakis J, et al. The department of veterans affairs' nsqip: The first national, validated, outcome-based, risk-adjusted and peer-controlled program for the measurement and enhancement of the quality of surgical care. 1998:491–507. J. A.
- [2]. Wiegmann D, ElBardissi A, Dearani J, Daly R, Sundt T. Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. 2007:658–665.
- [3]. Mazzocco K, Petitti D, Fong K, Bonacum D, Bookey J, Graham e. a. S. Surgical team behaviors and patient outcomes. 2009:678–685.
- [4]. Rydenfaelt C, Johansson G, Larsson P, Akerman K, Odenrick P. Social structures in the operating theatre: how contradicting rationalities and trust affect work. 2011
- [5]. Mitzenmacher, M.; Upfal, E. Probability and computing: randomized algorithms and probabilistic analysis. Cambridge University Press; 2005.

Fig. 1.
A system to predict the optimal surgical team

TABLE I

Complications rate of the personnel for the simulated environment

<i>P(role/member)</i>	1	2	3
surgeon	0.2	0.03	0.18
nurse	0.05	0.16	0.16
assistant	0.07	0.19	0.2

TABLE II

Number of failed procedures in 1000 procedures for each team

team	111	112	113	121	122	123	131	132	133	211	212	213	221	222	223	231	232	233	311	312	313	321	322	323	331	332	333
P	290	312	391	330	349	435	368	394	463	145	169	262	190	211	301	244	256	345	270	304	370	323	342	411	365	381	442

TABLE III

PROBABILITY OF FAILED PROCEDURE FOR ALL TEAMS

team	111	112	113	121	122	123	131	132	133	211	212	213	221	222	223	231	232	233	311	312	313	321	322	323	331	332	333
P	.29	.31	.39	.33	.35	.43	.37	.39	.46	.14	.17	.26	.19	.22	.30	.24	.26	.34	.27	.29	.37	.32	.34	.41	.35	.38	.44

TABLE IV

TEAM COMPLICATIONS WHEN A CERTAIN MEMBER IS IN

$P(member_{teams})$	1	2	3
surgeon	0.4113	0.2788	0.3889
nurse	0.3103	0.3849	0.3838
assistant	0.3030	0.3860	0.3900

TABLE V

Failure rates of the personnel for the simulated environment

<i>P(role/member)</i>	1	2	3
surgeon	0.3871	0.2491	0.3638
nurse	0.2820	0.3596	0.3584
assistant	0.2743	0.3607	0.3649

TABLE VI

Estimated complications rate of all possible teams of the simulated environment

team	111	112	113	121	122	123	131	132	133	211	212	213	221	222	223	231	232	233	311	312	313	321	322	323	331	332	333
P	.69	.70	.73	.70	.71	.75	.72	.73	.76	.62	.63	.67	.64	.65	.69	.66	.67	.71	.68	.69	.72	.70	.71	.74	.72	.72	.75