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Radiation safety culture quantification in radiation medicine practice with time-spatial decomposition binary equal weight stakeholder model

Abstract

Purpose: To quantitatively evaluate the radiation safety culture in radiation medicine practice with Temporal-Spatial Decomposition Binary Equal Weight Stakeholder Model.

Method and materials: A radiotherapy treatment procedure was decomposed based on Temporal-Spatial information by combination of different stakeholders which are physician, physicist, dosimetrist, therapist, nurses, patient, administrator and others. The procedure included three steps, which were simulation, treatment planning and dose delivery. And each step included different radiation safety control corresponding to patient, radiation worker and general public in different levels. The radiation safety culture traits could generate outcomes at different safety level and display in the binary format for the success of the process. Each stakeholder's weight in different radiation safety level would contribute to the overall score of the radiation safety level to patient, staff and general public. These quantified information were computed and optimized based on the decomposition function, which was represented by the product score and sums score determined by the temporal characteristics of the clinical procedure.

Results: Given the maximum number of safety culture trait at 9, two combinations of number of stakeholders and safety culture traits were calculated in simulation, treatment planning and dose delivery processes. For combination of maximum number of stakeholders and maximum number of traits, product scores were 3720087, 729 and 729; and sum scores were 72, 72, and 72; for minimum number of stakeholders and minimum number of traits, the product scores were 1, 1, and 1, and sum scores were 3, 3, and 3.

Conclusions: A simplified stakeholder model based on the temporal-spatial decomposed function was developed in describing radiotherapy treatment with the number of team members and culture traits implemented in binary mode. And this quantified methods of clinical procedures using radioactive materials and equipment provides potential for computer evaluation of complex clinical practice system.

Keywords: radiation safety culture, radiotherapy, clinical procedure, binary model

Volume 13 Issue 4 - 2022

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Received: July 14, 2022 | **Published:** July 25, 2022

Introduction

Since the discovery of the radiation,[1,2] the utilizations of the radiation have been benefited our society in different industries such as energy, medicine and society security. However, the side effect of radiation had also being recognized gradually with the improvement understanding the characteristics of the ionizing radiation. As a consequence, the safety of radiation worker, general public and patient is crucial in the environment of radiation medicine practice. After several unexpected disasters such as the 1986 nuclear accident at the Chernobyl nuclear power plant in the Ukraine[3] for energy generation and some incident in High Dose Rate brachytherapy in medical practice,[4] the U.S. Nuclear Regulatory Commission (USNRC) had recognized the important of building positive radiation safety culture including nine traits,[5] which are leadership safety values and actions, problem identification and resolution, personal accountability, work processes, continuous learning, environment for raising concerns, effective safety communication, respectful work environment, and questioning attitude. Besides USNRC, the radiation safety issue also had been addressed by different organizations such as in energy application such as The International Atomic Energy Agency,[6] safety in radiation medical practice such as AAPM.[7,8]

The positive radiation safety culture depends on the complexity and the function of the organization. The high level safety culture includes assessment and improvement or optimization methodology. And it is benefit to provide a system for evaluation, education and communication with different professionals, therefore, based on radiation safety culture policy statement issued by the U.S. Nuclear Regulatory Commission (NRC), a time-spatial decomposition binary stakeholder modal based on radiation safety culture traits was quantified for the implementation to radiation oncology routine practice for operation simulation and radiation safety training.

Materials and methods

A Radiotherapy Treatment Procedure was decomposed based on Time-Spatial information by combination of different stakeholders in each step. Each treatment time follows the time sequence of different steps during the procedure. The procedure includes simulation, treatment planning, and treatment plan dose delivery, which was shown in Figure 1.

Each step have different time-spatial-radiation safety related factors and corresponding stakeholders, which are physician, physicist, dosimetrist, therapist, nurses, patient, administrator and others. Each step includes different radiation safety control corresponding to patient, radiation worker and general public in different levels. For example, during simulation process, a CT simulator is usually applied, the radiation dose to patient, radiation workers, visitor around the CT room and so on. The radiation safety culture traits could generate different safety level outcome and most of time in the format of the success of the process. Technically speaking, scenarios such as scanned the wrong position of the patient, used the wrong protocol or so on. Each stakeholder's weight in different radiation safety level will contribute to the overall score of the radiation safety level to patient, staff and general public. These quantified information could be computed and optimized based on the decomposition function. Figure 2 shows the number of traits and related stakeholders used for this quantitative operation simulation.

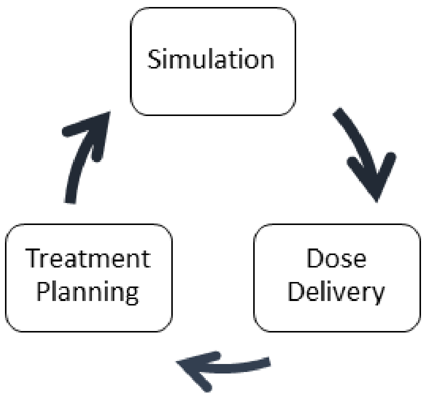

Figure 1 A routine clinical procedure cycle in a radiotherapy department.

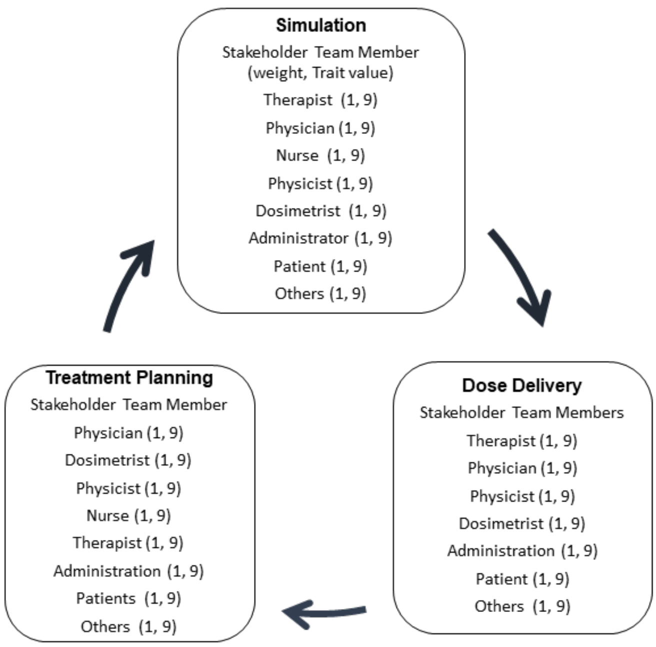

Figure 2 A stakeholder decomposition based on a clinical procedure cycle in radiotherapy department.

The quantitative value of the radiation safety culture practice could be computed with different methods, depending on the structure of the clinical procedure. In this study, the product score and sums score were selected due to the characteristics of the clinical procedure and related stakeholders. The temporal characteristics of the clinical procedure determined the series structures by different processes, which are corresponding to a temporal point.

When tasks in a process were executed simultaneously, the team members or stakeholders could be in different locations, so the quantitative value could be better described by sum score. Mathematically, a sum score could be expressed as following formula:

a. Individual member m with traits value V^m based on sum score

$$V^m == f(t) = F(T_i^m) = \sum_{i=1}^{N} T_i^m \qquad \text{(S\_1)}$$

Where, for member m, and culture trait $t^m \in [0,1]$ for the value is treated as a continuous function; culture trait T_i^m is 0 or 1, when binary approximation is applied. And N is total number of culture traits T.

b. Team g with traits value V^g with group weight W^g based sum score

$$V^g = f(w^g, t^g) = F(W_m^g, T_m^g) = \sum_{m=1}^{M} (W_m^g \times T_m^g) = \sum_{m=1}^{M} (W_m^g \times \sum_{i=1}^{N} T_m^g) \qquad \text{(S\_2)}$$

When V^g is treated as continuous function, weight W_m^g represents the weight of member m at group g. Low case t and capital case T represent the continuous and discrete culture traits. M is total number of in group g, and N is total number of culture trait implemented by a member m.

c. Radiation medicine procedure P with traits value V^p sum score

$$V^p = f(w^p, t^p) = F(W_g^p, T_g^p) = \sum_{g=1}^{G} (W_g^p \times T_g^p) = \sum_{g=1}^{G} (W_g^p \times \sum_{m=1}^{M} T_{gm}^p) = \sum_{g=1}^{G} (W_g^p \times (\sum_{m=1}^{M} W_{gm}^p \times (\sum_{i=1}^{N} T_{gmi}^p) \qquad \text{(S\_3)}$$

Where G is total number of group, M is total number of team. Other symbols are addressed at section a, and section b.

When tasks are distributed in different process, the practice team member and stakeholders could be in different locations at different temporal points. Therefore, the quantitative value could be better described by product score. Mathematically, a product score could be expressed as following formula:

a. Individual product score

$$V^m = f(t) = F(T_i^m) = \prod_{i=1}^{N} T_i^m \qquad \text{(P\_1)}$$

Where, for member m, continuous culture trait $t^m \in [0, 1]$, and discrete culture trait T_i^m is 0 or 1, and N is total number of culture trait.

b. Team trait weight product score chain

$$V^g = f(w^g, t^g) = F(W_m^g, T_m^g) = \prod_{m=1}^{M} (W_m^g \times T_m^g) = \prod_{m=1}^{M} (W_m^g \times \prod_{i=1}^{N} T_m^g) \qquad \text{(P\_2)}$$

In this formula, the symbol representations are the same as those address in formula (S_1), (S_2) and (S_3).

c. Radiation medicine procedure culture trait product score

$$V^p = f(w^p, t^p) = F(W_g^p, T_g^p) = \prod_{g=1}^{G} (W_g^p \times T_g^p) = \prod_{g=1}^{G} (W_g^p \times \prod_{m=1}^{M} T_{gm}^p) = \prod_{g=1}^{G} \{W_g^p \times [\prod_{m=1}^{M} (\prod_{i=1}^{N} T_{gmi}^p)]\} \qquad \text{(P\_3)}$$

In this formula, the symbol representations are the same as those address in formula (S_1), (S_2) and (S_3).

In practice reality, the following combination of sum and product score are plausible. In our operation simulation, the following formula was utilized;

$$V^p = f(w^p, t^p) = F(W_g^p, T_g^p) = \sum_{g=1}^{G} (W_g^p \times T_g^p) = \sum_{g=1}^{G} (W_g^p \times \prod_{m=1}^{M} T_{gm}^p) = \sum_{g=1}^{G} \{W_g^p \times [\prod_{m=1}^{M} (\sum_{i=1}^{N} T_{gmi}^p)]\} \qquad \text{(C\_1)}$$

Where the individual culture trait T is applied to sum score, the process traits were represented by product score, and the whole procedure was in the format of combination.

More generally, the formula addressed above could be expressed in the format or matrix give number of stakeholder m, number of team g, and number of process p.

To illustrate this quantification model, several simplifications were embedded. The procedure score was computed with maximum and minimum combination of the stakeholder team based on the number of member in the team and number of traits of individual number and their combinations. The structures for these combination war chain or links. So a sum score or product score were used to simulate these structures for quantification evaluation.

Results

A completed two dimensional combination structure in table 1. For simplification, the numerical computation of the simulation was only done on the following two situations:

Table 1 Basic combination of scores of stakeholders and radiation safety culture traits for quantitative computation

Culture traits\Stakeholder	Minimum (Min) number of Stakeholders	Maximum (Max) number of Stakeholders
Minimum (Min) number of traits	Min+Min (Sum) MinXMin (Product)	Min+Max (Sum) MinXMax (Product)
Maximum (Max) number of traits	Max+Min (Sum) MinXMax (Product)	Max+Max (Sum) MaxXMax(Product)

Equal Weight Binary model with 9 traits with combination of maximum number of stakeholders and maximum number of traits

The results are showed in figure 3. For the maximum number of team member with maximum number of trait for a Radiation treatment procedure was with product score is 3720087, 729 and 729; and sum score is 72, 72, 72 in simulation, treatment planning and dose delivery procedure.

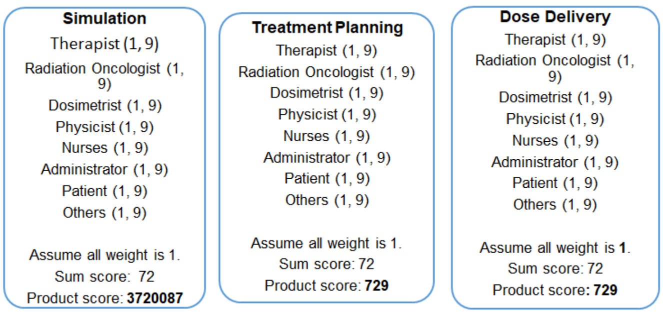

Figure 3 Scores based on maximum number of stakeholder and maximum number of radiation safety culture traits.

Equal Weight Binary model with 9 traits with combination of minimum number of stakeholders and minimum number of traits

When the procedure involved only minimum number of stakeholders and minimum number of culture traits, the scenario is similar to one professional represented the whole team. The computation result is showed in figure 4.

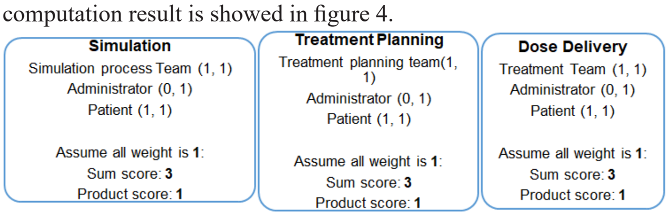

Figure 4 Scores based on minimum number of stakeholder and minimum number of radiation safety culture traits.

Discussion

A simplified stakeholder model based on the time-spatial decomposed function was used in monitoring the efficacy of radiation medicine treatment with the number of team member and culture traits. And this model provide a qualified optimization tool for evaluation the efficacy of radiation medicine practice. When social economic factors and other stakeholders are considered, this method could be implemented in other radiation safety related procedure or environment for optimal monitoring the quality of operation with computer-driven simulation for decision-making and provide data collecting mathematical model.

In practice, only quantitative score number is positive the radiation safety is operated normally. In binary mode, positive mode corresponding to 1, and negative mode means 0. Continuous practice in negative mode could result in mal-practice or radiation safety issue in certain time span. For empirical information, analysis of big data from different practice center could reach an efficacy of the practice pattern in targeting radiation safety department.

For implementation, a series structure and parallel stricture could be programmed with input interface of stakeholder and safety culture traits. The number of stakeholder and safety culture traits could change the sum score or product score value. Mathematically, it is possible to find an optimal score value. Other factors such as cost of each stakeholder, expense of the culture treat practice, changes of stakeholders, and variation of culture features could further improve the usage of this stakeholder binary safety culture model.

Acknowledgments

None.

Conflicts of interest

Author declares that there is no conflict of interest.

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Citation: Kaile L. Radiation safety culture quantification in radiation medicine practice with time-spatial decomposition binary equal weight stakeholder model. *J Cancer Prev Curr Res*. 2022;13(4):94–96. DOI: 10.15406/jcpcr.2022.13.00495