THE ISRAEL NATIONAL INSTITUTE FOR HEALTH POLICY RESEARCH

Title of research (in English)

Promoting Patient safety and near miss reporting - a game theory approach

Title of research (in Hebrew)

קידום בטיחות הטיפול באמצעות דיווחי כמעט אירוע - גישה מבוססת תורת המשחקים

Executive Summary- Hebrew

הרקע המדעי:

קידום בטיחות הטיפול הוא נושא המעסיק הן את קובעי המדיניות והן את המטפלים במערכות הבריאות בעולם כולו. משרד הבריאות פועל באמצעים רבים לקידום בטיחות המטופל והמטפל ולמניעת טעויות וכשלים מערכתיים (מתוך אתר משרד הבריאות (https://www.health.gov.il/UnitsOffice/HD/HQD/safety/Pages/default.aspx).

אירוע "כמעט ונפגע", "Near Miss" או "כמעט אירוע" בהגדרות משרד הבריאות, מוגדר כהתרחשות בתהליך הטיפולי עם פוטנציאל לנזק או טעות, שנעצרה טרם הגעת האירוע או הכשל למטופל והסתיימה ללא פגיעה או נזק. במידה וכן התממש, היה מתרחש "אירוע חריג". שני המצבים עשויים להוות חיישן לכשל מערכתי העלול להוביל לתוצאות עתידיות חמורות, אך ההבדל נעוץ בעובדה כי "כמעט אירוע" עשוי להצביע על כשל מערכתי עוד בטרם יתרחשו כלל אירועים חריגים. יש להניח כי דיווח על התרחשותו של "כמעט אירוע" שכזה במערכת הבריאות וטיפול ראוי בו יביאו לשיפור משמעותי בכל הקשור לאמינות, בטיחות ואיכות הטיפול (Barach & Small, 2000; Shaw et al., 2005).

דיווח על "כמעט אירועים" בבתי החולים נחוץ על מנת למנוע טעויות, לשפר את תהליכי העבודה ולהקטין את הסיכון לתמותה ותחלואה, ומהווה כלי בקרה והשוואה בין מחלקות ו/או בתי חולים. בדו"ח המסכם של משרד הבריאות לשנים 2017-2019 הוצג מודל להערכת בטיחות הטיפול בבתי החולים הכלליים שמשווה בתי חולים באמצעות מדד דיווח על "כמעט אירועים" (מדד 7) ולמידה מאירועים חריגים (מדד 8). למרות זאת, דיווח על "כמעט אירועים" לא הפך עדיין לחלק אינטגרלי מתרבות הדיווח בכל המוסדות הרפואיים בישראל. בסקר תרבות בטיחות ארגונית בבתי החולים הכלליים בישראל נמצא כי 51% מאנשי הצוות מפחדים לדווח על טעויות שאירעו להם בעבודתם (זוהר, עין גל, דידי וצדיק, 2016).

מודלים של קבלת החלטות מבוססי תורת המשחקים מאפשרים ניתוחי עומק של התנהגות ה"שחקנים" השונים -הנהלה, הצוות המטפל - בכל הקשור לדיווחים על אירועי "כמעט ונפגע" וניתוחם. הטמעת תרבות ארגונית המעודדת בדיקה של אירועי "כמעט ונפגע" מביאה לשיפור משמעותי בכל הקשור לבטיחות, כמו גם להקטנת עלויות וחיסכון כספי לארגון.

יישום תורת המשחקים לשיפור הבטיחות הינו תחום מחקר חדשני ומבטיח. רק בשנים האחרונות פורסמו מספר מאמרים רלוונטיים. Liu et al. (2015) פיתחו משחק אבולוציוני כדי לשפר את בטיחות מכרות הפחם. Ma and Zhao (2018) הציגו מודל משחק העוסק ביעילות הבקרה וההסדרה של הבטיחות, וניתחו את השפעת האינטראקציה בין הממשלה והחברות בסין. Liu et al. (2019) ניסחו משחק אבולוציוני רב-משתתפים לניתוח החלטות הקשורות להסדרת הבטיחות במכרה פחם, וניתחו את ההשפעות של יישום אסטרטגיות עונש שונות על תהליך המשחק ועל שיווי המשקל במשחק.

למיטב ידיעתנו, מודלים של תורת המשחקים לשיפור בטיחות באמצעות דיווחי "כמעט אירועים" פותחו רק לאחרונה Winkler, M., Perlman, Y., & Westreich, S. (2019); Barrachina, A., & González-Chordá, V. M. (2020); Westreich, S. Perlman, Y., & Winkler, M., (2021)

מטרת המחקר:

פיתוח מתודולוגיה מבוססת תורת המשחקים להטמעת תרבות דיווח אירועי "כמעט וניפגע", תחקור והפקת לקחים, יישום והפעלת תהליכי תיקון.

שיטה:

פיתוח מודל מתמטי מבוסס על תורת המשחקים בו ה"שחקנים" הם הצוות המטפל והנהלת בתי החולים. מידול מתמטי של הרצון של הצוות המטפל לדווח כמשתנה מקרי.

ממצאים:

מהצד התיאורטי שלושה משחקים פותחו: משחק סטטי, משחק בייסיאני ומשחק אבולציוני.

מהצד המעשי הוכחו ההשערות הבאות

1. לשיתוף פעולה של ההנהלה והצוות המטפל - רופאים, סיעוד, פרה-רפואיים, צוות מנהל ומשק - בכל הקשור לדיווח, הערכת הסיכון וקבלת החלטות ביחס ל"כמעט אירועים", יש פוטנציאל לשיפור בטיחות הטיפול. מודלים מבוססי תורת המשחקים מאפשרים ניתוח אנליטי של שיתופי פעולה כאלו.

2. ניתן, באמצעות תמריצים ממוקדים לצוות המטפל ושינוי תהליכי עבודה, להגדיל את שיעור הדיווח ואיכות הדיווח.
3. ביצוע תהליך למידה / תחקור של "כמעט אירועים" ו"אירועים חריגים" יוביל לביצוע פעולות מתקנות למניעת טעויות וכשלים מערכתיים.

המלצות לקובעי מדיניות:

המודל שפותח מאפשר לקבוע תהליכים המותאמים למחלקה, לתהליך הרפואי ולסיכונים התורמים להגדלת שיעור דיווח "כמעט אירועים", להקטנת הסבירות לאירועי בטיחות ותאונות בעתיד לשיפור בטיחות הטיפול, וכן יכול לשמש ככלי לקביעת תמריצים ממוקדים לאנשי הצוות המטפל כנגזרת מהסיכונים ורמת הבטיחות הנדרשת.

רשימת המקורות

Barach, P., & Small, S. D. (2000). Reporting and preventing medical mishaps: lessons from non-medical near miss reporting systems. Bmj, 320(7237), 759-763.

Barrachina, A., & González-Chordá, V. M. (2020). Error reporting and the performance of nursing management: a game-theoretic study. *IMA Journal of Management Mathematics*, *31*(4), 445-468.

Liu, D., Xiao, X., Li, H., & Wang, W. (2015). Historical evolution and benefit–cost explanation of periodical fluctuation in coal mine safety supervision: An evolutionary game analysis framework. European Journal of Operational Research, 243(3), 974-984.

Liu, Q., Lia, X., & Meng, X. (2019). Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in China based on system dynamics. Safety Science, 111, 224-233.

Ma, Y. & Zhao, Q. (2018). Decision-making in safety efforts: Role of the government in reducing the probability of workplace accidents in China. Safety Science, 104, 81-90.

Shaw, R., Drever, F., Hughes, H., Osborn, S., & Williams, S. (2005). Adverse events and near miss reporting in the NHS. BMJ Quality & Safety, 14(4), 279-283.

Westreich, S., Perlman, Y., & Winkler, M. (2021). Analysis and implications of the management of near-miss events: a game theoretic approach. *Reliability Engineering &*

Winkler, M., Perlman, Y., & Westreich, S. (2019). Reporting near-miss safety events: Impacts and decision-making analysis. Safety science, 117, 365-374.

עקב זוהר,ע. , עין גל,י. ,דידי, א., צדיק, א. (2016). תרבות בטיחות ארגונית מגמות בזמן 2012-2015 סקר בבתי חולים כלליים. האגף להבטחת איכות, המחלקה למבדקי איכות,

Comprehensive scientific report - English

- **Scientific background:**

Medical errors are a serious public health problem and a leading cause of death in the United States (Rodziewicz, 2021). Promoting patient safety can be enhanced by establishing near-miss reporting systems detecting events which could have become catastrophic but did not, either by chance or because someone or something intervened (ElKhider and Savage, 2019). Potential benefits of using near-miss reporting systems include learning from adverse events and creating a treatable warning signal, which serves as a management tool for improving patient safety and may also save financial resources (Archer et al., 2017; Health Quality Ontario 2017).

It is generally agreed that a reporting culture should be a significant component of any system that involves patient safety. Indeed, many hospitals in countries throughout the world encourage their workers to report near-misses, adverse events, or sentinel events to an in-hospital reporting system or sometimes even to a national-level reporting system. However, despite efforts to establish such reporting systems, several studies have identified an alarmingly low near-miss reporting rate. These low levels of reporting make it difficult to identify and prioritize patient safety risks and to learn from near-miss incidents. Reducing the under-reporting poses a significant challenge due to several barriers to in-hospital reporting, including fear of blame, insufficient feedback to those reporting near-misses, lack of organizational support, and workers' perception that reporting does not result in an improvement of patient safety. Nonetheless, it is possible for hospitals to motivate reporting, and they can do so in a variety of ways. For example, training workers to understand what and how to report, giving enhanced feedback on statistics of recently reported events, and/or describing hazard control strategies developed from recent analyses. Although these different barriers and drivers to in-hospital reporting have been examined in several empirical studies, there is a lack of appropriate mathematical models that investigate the dynamics of decision-making among members of staff and management and its impact on the rate of reporting.

Although a substantial stream of literature focuses on near-miss reporting within healthcare organizations as a strategy to reduce preventable patient harm and improve patient safety [see the literature review of Archer et al. (2017)], there is a paucity of research on this topic using a game theoretic approach. Only a limited number of papers have applied game theory to investigating the dynamics between management and staff and the impact of reporting near-miss events on safety. For example, Winkler et al. (2019) developed a theoretical near-miss event game that models' decisions on reporting near-miss-events made by a manager and an employee, where the model assumptions were drawn from an empirical study. Westreich et al. (2021) proposed another game theoretical model whose aims were to minimize the likelihood of future accidents and to reduce costs. The authors concluded that encouraging behavioral changes in employees can be achieved by increasing their inherent motivation, creating an organizational culture that encourages reporting, increasing employees' estimated penalty in case of non-reporting, and decreasing his estimated loss due to reporting.

Willingness to report is an essential ingredient of a culture of reporting. It was hsown that non-punitive learning, system-driven error management and effective feedback and quality improvement from the reporting, results in a high willingness to report (Chiang et al., 2018; Morrison et al., 2018). Ebrahim and Ismail (2021) conducted an empirical study and found a positive correlation between nurses' willingness to report near-misses and their perception of patient safety. Moreover, nurses generally showed a moderate willingness to report near-misses and a moderate perception of patient safety culture.

In addition to the staff willingness to report, research shows that hospital management actions have a high impact on reporting rates. Petschnig (2017) argues that if near-miss reporting system is not supported by higher managers in health care organizations, it will be implemented with trouble and will not produce any quantifiable safety improvement. On the other hand, confidentiality of the reporters and blame-free culture might improve and support the nurse's involvement in near-miss events reports (Dyab et al., 2018). Leadership is a critical element to the success of event reporting. ElKhider and Savage (2019) suggest that that feedback should be given to the staff member who reported the event, clarify which near-misses need to be reported, simplify the process, and incentives to reporters. Aaron (2020) reports that management can educate resident on their professional duty to report and when incentives were used near-miss reporting behaviors improved. Uibu (2020) recommend that hospitals can increase reporting rates by providing systematic feedback to the whole organization, ensuring education and resources for near-miss reporting an implementing follow-up activity. Mangers' actions have also an important role in promoting patient safety. Implementing a prioritization framework (leveraging the concepts of Failure Modes Effect Analysis and Analytic Hierarchy Process) enable hospital management to identify events of greatest risk and invest resources for analysis and mitigation (Liszewski, 2020).

To the best of our knowledge, the study of Barrachina and González-Chordá (2016) is among the very few applying a game model to near-miss reporting by nurses in a healthcare system. They presented a principal-agent model in which the principal (the nurse manager) asks the agent (the nurse) to perform a task on a certain patient. The nurse decides whether to report to the manager a mistake she has made, in the knowledge that the manager can later observe whether the patient has suffered from the accident. The authors considered four styles of error reporting and analyzed the interactions between different leadership styles of the manager and each style of the nurse. Calculating the equilibrium for each combination enabled them to evaluate which of the four leadership styles is the best for error reporting.

- **Research objectives:**

By formulating various types of game theoretical models, this research aims to study the dynamics between staff and management regarding the reporting of near-miss events by the staff and the level of handling the reports by the management. The results of these dynamics will be the rate of reporting on one hand and level of investment (and the resulting expenses) of the management on the other. Gaining some control on the rate of reporting will allow an efficient managing of the reporting system and will thus contribute to the safety culture of the Health-care organization.

- **Methodology:**

We formulate a game model based on the following. Staff members decide whether to report a near-miss event or to ignore it, and the management decides on its attitude to the report. That is, whether to handle the report thoroughly or poorly. The staff member’s decisions are driven from the reward for reporting, determined by the individual’s willingness to report on one hand and the management’s attitude towards reporting on the other. We assume that willingness to report is randomly distributed among the staff members. The management attitude towards reporting is expressed by means of studying, analyzing, drawing conclusions, providing feedback, and taking necessary actions if required. The extent of handling the reports is determined by the cost of handling the reports and their impact on the expected damage in case of disaster or a serious mistake. Three types of models are constructed. (a) A stage game, where the staff members' willingness to report is given; (b) a Bayesian game, where Staff members are distributed by types, depending on their willingness to report near-misses and the management acts according to its beliefs about the staff member type; and (c) an evolutionary game that includes two populations with different payoff matrices.

Parameters and notations.

D_O - The original estimation of the expected damage associated with a future accident.

D_R - The estimated expected damage given that a near-miss event was reported and then poorly treated. We thus assume:

C_0 - A caring management’s costs endures by the reporting system.

C_1 - Extra cost for thoroughly handling reported events.

$v(x)$ - A value function, increasing with a diminishing rate, that describes the impact of investing extra cost x in thoroughly handling reported events on the estimated expected damage if poorly handled.

ω - A parameter describing willingness to report of a staff member. This parameter may either be known to the management, or a random variable whose distribution is given.

$r_c(\omega)$ - The reward for reporting for a staff member with willingness to report ω, when his managers thoroughly invest in reports.

$r_p(\omega)$ - The reward for reporting for a staff member with willingness to report ω, when his managers poorly invest in reports.

a - The objective cost of reporting

<u>Assumptions</u>:

1. $D_O \geq D_R$
2. $0 < C_0 < C_1$.
3. $\frac{\partial r_c}{\partial \omega} > \frac{\partial r_p}{\partial \omega} > 0$ and $r_c(0) = r_p(0) = -a < 0$

<u>The stage matrix</u>

The normal form game is given by the following payoffs matrix

	Employee reports	Employee does not report
Caring management thoroughly handles	$D_R - v(C_1) + C_1,\ r_c(\omega)$	$D_o + C_0, 0$
Management poorly handles	$D_R,\ r_p(\omega)$	$D_o, 0$

The expenses of each party at mixed strategies, when the rate of reporting by the staff members is p and the management thoroughly invests in reported events with probability q, is given by:

Management expenses - $U_m(q,p) = p\big((\mathrm{C}_1 - v(C_1) - C_0)q - D_O + D_R\big) + q\,\mathrm{C}_0 + D_O$

Staff payoff - $U_s(q,p) = p\left(q \cdot (r_c(\omega) - r_p(\omega)) + r_p(\omega)\right)$

- **Findings:**

When we regard willingness to report as a parameter known to the management, we have two propositions:

Proposition 1. There are two possible Nash equilibrium points in pure strategies and one in mixed strategies.

(i) If $r_c(\omega) < 0$ then the employee never reports, hence $p^* = 0$ and so $q^* = 0$ and $U_m(0,0) = D_O$, $U_s(0,0) = 0$

(ii) If $r_p(\omega) > 0$ then the employee always prefers to report, that is, $p^* = 1$. By non-degeneracy also $q^* = 1$, and so,
$U_m(1,1) = D_R - v(C_1) + C_1$, $U_s(1,1) = r_c(\omega)$.

(iii) If $r_c(\omega) > 0$ and $r_p(\omega) < 0$, we have a unique mixed strategies equilibrium

$p^* = \frac{C_0}{v(C_1) - C_1 + C_0}$, $\quad q^* = \frac{-r_p(\omega)}{r_c(\omega) - r_p(\omega)}$, and then

$$U_M(q^*, p^*) = D_O - \frac{C_0(D_O - D_R)}{v(C_1) - C_1 + C_0} = D_O - p^*(D_O - D_R), \qquad U_S(q^*, p^*) = 0$$

Proposition 2**:** In a Stackelberg model with the management as a leader,

If $D_R - v(C_1) + C_1 < D_O$ then $\quad q_{ml}{}^* = 1,\ p_{ml}{}^* = 1$ and $U_m(1,1) = D_R - v(C_1) + C_1$

If $D_R - v(C_1) + C_1 > D_O$ then $\quad q_{ml}{}^* = 0,\ p_{ml}{}^* = 0$ and $U_m(0,0) = D_O$

When we regard ω as a random variable with cumulative distribution function F_ω, we find that, Proposition 4: Assume willingness to report is randomly distributed with cumulative distribution function F_ω. Let $p^* = \frac{C_0}{v(C_1) - C_1 + C_0}$.

(i) If $F_\omega^{-1}(1-p^*) \le r_c^{-1}(0)$ then necessarily $p^* = 0$, $(0,0)$ is the equilibrium point and $U_m(0,0) = D_O$, $U_s(0,0) = 0$

(ii) If $F_\omega^{-1}(1-p^*) \ge r_p^{-1}(0)$ then necessarily $q^* = 1$, $(1,1)$ is the equilibrium point and $U_m(1,1) = D_R - v(C_1) + C_1$, $U_s(1,1) = r_c(\omega)$ for a staff member of type ω.

(iii) If $r_c^{-1}(0) < F_\omega^{-1}(1-p^*) < r_p^{-1}(0)$, then mixed strategies Bayesian Nash equilibrium is obtained when

$$p^* = \frac{C_0}{v(C_1) - C_1 + C_0} \qquad q_f^* = \frac{-r_p(F_\omega^{-1}(1-p^*))}{r_c(F_\omega^{-1}(1-p^*)) - r_p(F_\omega^{-1}(1-p^*))}$$

In this case $U_M(q_f^*, p^*) = D_O - \frac{C_0(D_O - D_R)}{v(C_1) - C_1 + C_0} = D_O - p^*(D_O - D_R)$.

When we analyze the evolutionary game and its dynamics, we show that for a known value of willingness to report ω,

Proposition 5: The evolutionary game based on the payoff matrices $-\mathbf{U}_m$ and $\mathbf{U}_s^T$ has four fixed points $(1,0),(0,1),(0,0),(1,1)$. Furthermore,

(i) If $r_c(\omega) > 0$ and $r_p(\omega) < 0$, then $(0,0)$ and $(1,1)$ are asymptotically stable fixed points. In addition, the point (q_ω^*, p^*) where $q_\omega^* = \frac{-r_p(\omega)}{r_c(\omega) - r_p(\omega)}$ and $p^* = \frac{C_0}{v(C_1) - C_1 + C_0}$, is another fixed point that has a stable limit cycle but is not asymptotically stable.

(ii) If $r_c(\omega) < 0$, then we do not have a mixed strategies fixed point. The point $(0,0)$ is a unique asymptotically stable fixed point.

(iii) If $r_p(\omega) > 0$, then and we do not have a mixed strategies fixed point. The point $(1,1)$ is a unique asymptotically stable fixed point.

When $r_c(\omega) > 0$ and $r_p(\omega) < 0$, the trajectories for the replicator dynamics at (q_ω^*, p^*) are given by

$$q_t = q_\omega^* + A \cdot \cos(\theta t + \delta)$$
$$p_t = p^* + A \cdot \sin(\theta t + \delta)$$

Where $\theta = \sqrt{\frac{C_0 (v(C_1) - C_1) \cdot r_p(\omega) \cdot r_c(\omega)}{\left(C_0 + v(C_1) - C_1\right)(r_c(\omega) - r_p(\omega))}}$,

(q_0, p_0) is the initial state, $q(0) = q_0 - q^*$, $p(0) = p_0 - p^*$, $A = \sqrt{q(0)^2 + p(0)^2}$ and

$$\delta = \begin{cases} arctg(\frac{q(0)}{p(0)}) & if \ \frac{q(0)}{p(0)} > 0 \\ \pi + arctg(\frac{q(0)}{p(0)}) & if \ \frac{q(0)}{p(0)} \le 0 \end{cases}$$

When we consider ω as a random variable, the evolutionary game yields,

Proposition 6: The evolutionary game based on the payoff matrices $-\mathbf{U}_m$ and $\mathbf{U}_s^T$ with cumulative distribution function F_ω, has the following possible fixed points:

(i) If $r_c(\omega) < 0$ for all ω, then the point $(0,0)$ is a unique asymptotically stable fixed point.

(ii) If $r_p(\omega) > 0$ for all ω, then the point $(1,1)$ is a unique asymptotically stable fixed point.

(iii) Otherwise, the point $(\tilde{q}, \tilde{p})$,

$$\tilde{q} = 1 - F_\omega(r_p^{-1}(0)) + \left(F_\omega(r_p^{-1}(0)) - F_\omega(r_c^{-1}(0))\right) q_f^*$$
$$\tilde{p} = 1 - F_\omega(r_p^{-1}(0)) + \left(F_\omega(r_p^{-1}(0)) - F_\omega(r_c^{-1}(0))\right) p^*$$

Where $q_f^* = \frac{-r_p(F_\omega^{-1}(1-p^*))}{r_c(F_\omega^{-1}(1-p^*)) - r_p(F_\omega^{-1}(1-p^*))}$ and $p^* = \frac{C_0}{v(C_1) - C_1 + C_0}$, is the expected fixed point that has a stable limit cycle (but is not asymptotically stable).

The trajectories for the replicator dynamics at $(\tilde{q},\tilde{p})$ are given by

$$\tilde{q}_t = \tilde{q} + \tilde{A}\cdot\cos(\theta t+\delta)$$
$$\tilde{p}_t = \tilde{p} + \tilde{A}\cdot\sin(\theta t+\delta)$$

Where $\theta = \sqrt{\dfrac{C_0(v(C_1)-C_1)\cdot r_p(\omega)\cdot r_c(\omega)}{\left(C_0+v(C_1)-C_1\right)(r_c(\omega)-r_p(\omega))}}$, $\quad r_p^{-1}(0) < \omega < r_c^{-1}(0)$,

(q_0, p_0) is the initial state, $\begin{array}{l}\tilde{q}(0) = \left(F_\omega(r_p^{-1}(0)) - F_\omega(r_c^{-1}(0))\right)q_0 - \tilde{q} \\ \tilde{p}(0) = \left(F_\omega(r_p^{-1}(0)) - F_\omega(r_c^{-1}(0))\right)p_0 - \tilde{p}\end{array}$,

$\tilde{A} = \sqrt{\tilde{q}(0)^2 + \tilde{p}(0)^2}$ and

$$\delta = \begin{cases} arctg(\dfrac{\tilde{q}(0)}{\tilde{p}(0)}) & if \ \dfrac{\tilde{q}(0)}{\tilde{p}(0)} > 0 \\ \pi + arctg(\dfrac{\tilde{q}(0)}{\tilde{p}(0)}) & if \ \dfrac{\tilde{q}(0)}{\tilde{p}(0)} \le 0 \end{cases}$$

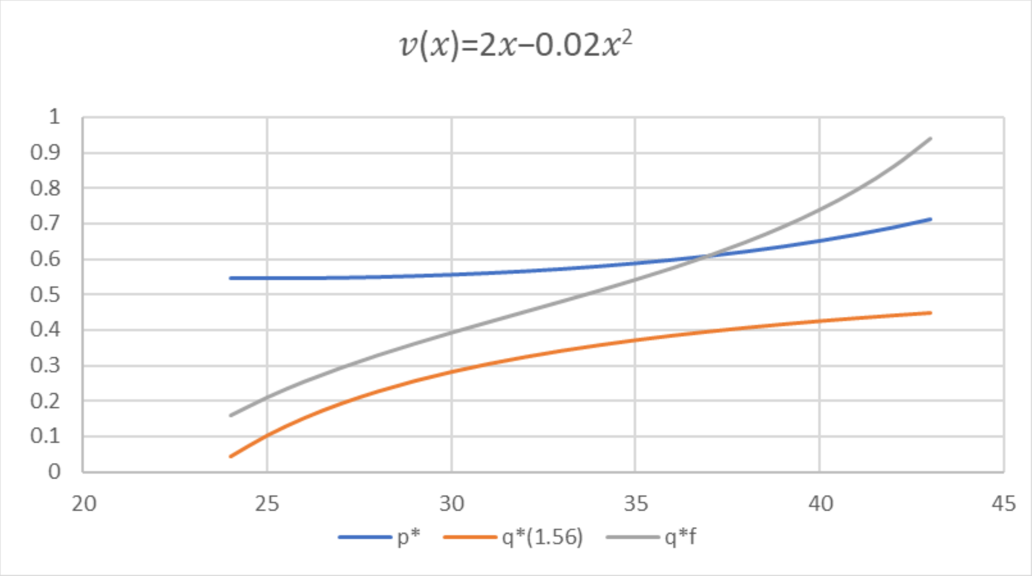
<u>Numerical findings</u>

We performed some numerical studies based on empirical research conducted by Ebrahim and Ismail (2021) who explore nurses' willingness to report and their perception of patients' safety culture. The following figures describe our results.

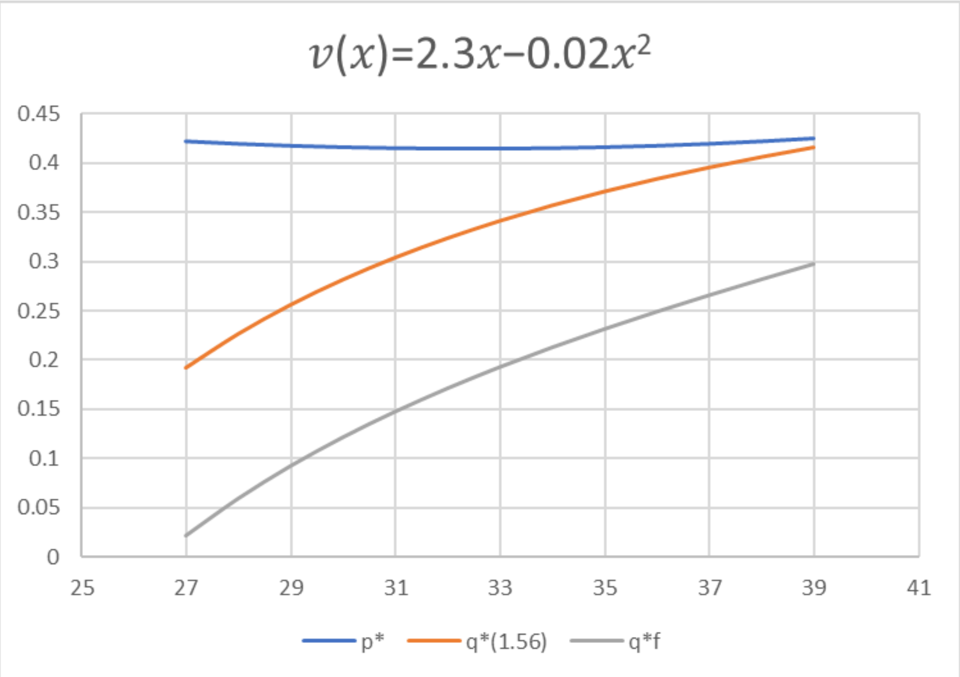
Fig.1 and 2 outline the impact of the extra cost C_1 on the rate of reporting at equilibrium p^*, the level of handling report, $q^*_{E[\omega]}$ and the level of handling reports, q^*_f, when considering willingness as a random variable We use the set of values:

$$E[\omega]=1.56, \quad a=1, \quad , C_0=15 \ , \quad \alpha=\frac{C_0}{C_1}$$

For Fig. 1 we assume $v(x)=2x-0.02x^2$. Focusing on the range where there exist non-trivial mixed strategies equilibrium, we take values of C_1 in the range $[16,43]$. We see that p^* increases in the given range and that $q^*_f > q^*_{1.56}$



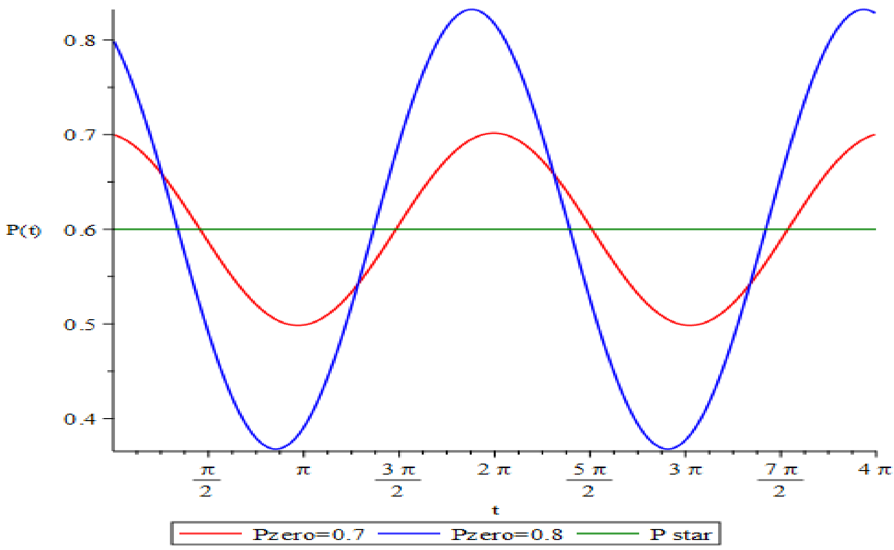
However, the behavior of $p^*, q^*_{E[\omega]}$ and q^*_f depend on the value function $v(x)$. If we take $v(x) = 2.3x - 0.02x^2$, then there is a mixed strategies equilibrium when C_1 varies in the range $[44, 56]$. In Fig.2 we see that in this range, p^* has a minimum, the shape of the increasing q^*_f has changed, and moreover, $q^*_f < q^*_{1.56}$

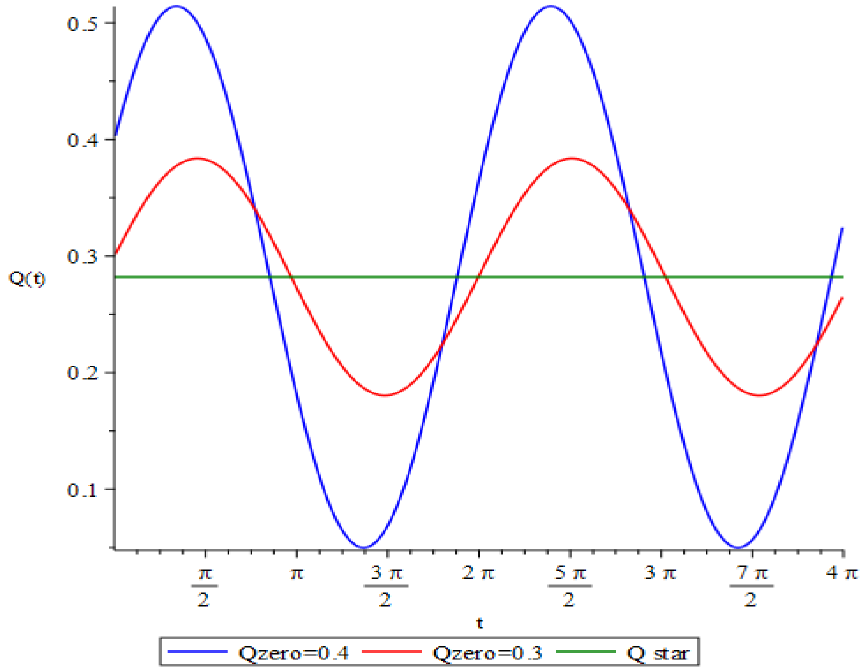


We then perform numerical study for the evolutionary game. We first study the stable point (q^*, p^*) when willingness to report is considered as $E[\omega]=1.56$, hence satisfies $a < E[\omega] < \frac{a}{\alpha}$. In this case the mixed equilibrium point $\left(q^* = \frac{a-\alpha\omega}{(1-\alpha)\omega}, p^* = \frac{C_0}{v(C_1)-C_1+C_0} \right)$ is a stable point for the system of differential with a stable limit cycle.

In Fig. 3 and 4 we describe the respected trajectories of q_t and p_t for two different initial values (q_0, p_0). We use the following set of values

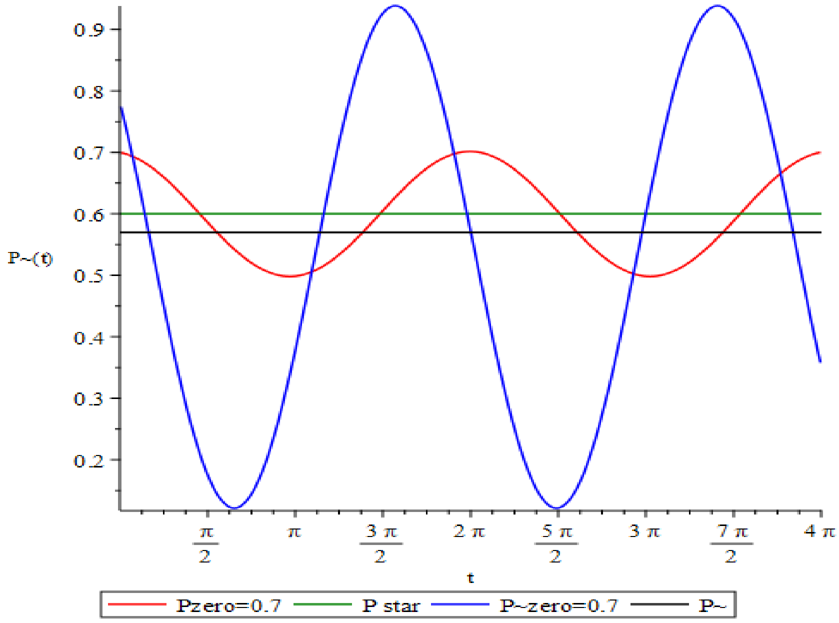
$$a=1, \ , C_0=15, \quad C_1=30, \ v(C_1)=42, \quad \alpha=\frac{C_0}{C_1}=0.5 \quad E[\omega]=1.56.$$

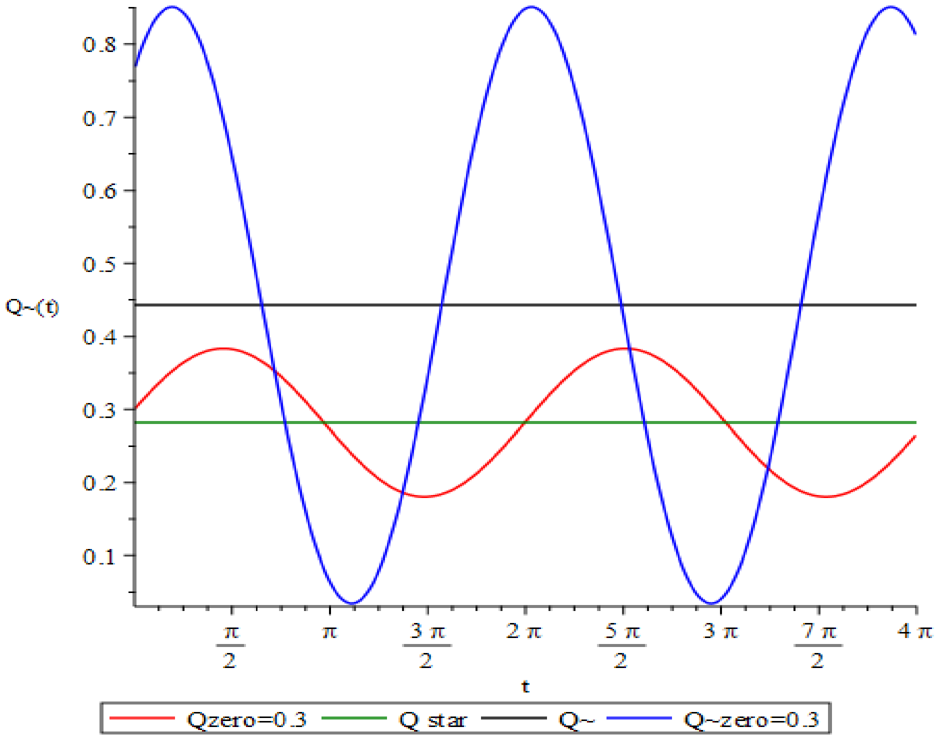




Consider now willingness to report as a random variable. In Fig. 5 and 6, we describe the respected trajectories of $\tilde{q}_t$, $\tilde{p}_t$ for the set of values

$$a=1, \ , C_0=15, \quad C_1=30, \quad v(C_1)=42, \quad \alpha=\frac{C_0}{C_1}=0.5 \quad E[\omega]=1.56.$$





- **Discussion and Conclusions:**

The rate of reporting at mixed strategies Nash equilibrium and the management expenses do not depend on willingness to report of the staff members, but on the cost of maintaining a reporting system and the extra cost caused when investing in thoroughly treating reports. When the rate of reporting is higher, an achievement desired on its own, the management expenses are also lower. Hypothetically, the management can control the rate of reporting by determining the extra cost. Yet, the impact of increasing the extra cost is measured by a value function, which may or may not increase the rate of reporting, depending on the behavior of. Anyhow, in the current model we do not refer to the extra cost as a decision variable of the management, but as a given parameter.

The staff members' willingness to report and the resulting personal reward, affect the required level of the management's investment in handling reports at the equilibrium. The level is weighted between 0 (poor) and 1 (thorough). The higher the staff willingness, the lower the required level of the management's investment. The management may affect willingness to report and the personal reward indirectly, by educational activity, incentives, and encouragements. The management can however decrease its level of investment directly by decreasing the objective cost of reporting. This can be done for example by applying an efficient system of reporting, which will make it easier for the staff to fill out appropriate reports.

When the staff willingness to report is a random variable, the management acts based on its beliefs regarding the strategies and payoffs of the staff. The rate of reporting at equilibrium, and the management expenses are the same for the random case and for the known one parameter willingness. This is no longer true for the level of the management's investment at equilibrium, q_f^*, regarding the random variable willingness to report. The level of the management investment depends on the distribution of willingness among the staff. Explicitly, it results from the percentile $1-p^*$ of the distribution of willingness to report, where p^* is the rate of reporting at equilibrium.

The evolutionary model provides similar insights with somewhat different emphases. The edge cases, in which the rewards for willingness to report are very low or very high, will lead in the long term to the respective edge results of zero or full reports. In the common case when willingness to report is a known parameter ω, the dynamics has a fixed point (q_ω^*, p^*), which is not asymptotically stable, identical to the mixed strategies equilibrium point. The fixed point shares its properties and the sensitivities described above. We find moreover, a periodic fluctuation around it.

When willingness to report is considered a random variable, the expected fixed point, $(\tilde{q}, \tilde{p})$, results from (i) the weight of the very low values of willingness that converge to zero reporting and zero treating, (ii) the weight of very high values of willingness that converge to full reporting and full treating reports, and (iii) the remaining (common) weight that generate periodic fluctuations around (q_f^*, p^*), the mixed strategies equilibrium point. The amplitude around the expected fixed point is the same amplitude as above, multiplied by the weight of common willingness.

- **Policy Implications and Recommendations:**

Under the assumption that the management's objective is to increase the rate of reporting, thorough treating of the reports usually causes the desired reaction, either as best response or evolutionarily. However, if the reward for reporting, which depends among the rest on the initial willingness to report, is too low, even full treating may be unusable. In this case, the management should find ways to increase the reward for reporting. This may be done by either decreasing the objective cost of reporting, or increasing willingness to report in all possible ways – education, safety culture, feedback etc.

When the management's objective is minimizing expenses, while increasing reports is a secondary outcome, then the rate of reporting arises as equilibrium of a game or a steady point of a certain dynamics. Yet, the implications on the management behavior are similar.