Hanoi University Studies

APPLICATION OF GAME THEORY TO CHOOSE STRATEGY FOR ENTERPRISES IN THE PANDEMIC SITUATION USING SPEA2 ALGORITHM

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Abstract

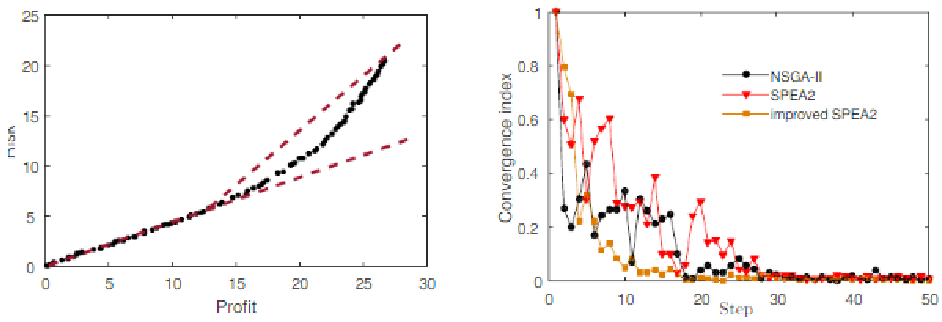
The Covid pandemic has had a tremendous impact on businesses, has turned the world upside down, and has had a significant impact on the economies of countries in general and enterprises in particular. Finding a strategy for businesses to guarantee the safety and health of their employees is critical because it will allow enterprises to continue to develop steadily, more importantly; it is about profit improvement and seeking potential in the face of the COVID-19 outbreak. To tackle this issue, this research provided a model and algorithm. In this work, we used game theory to develop disease prevention solutions for businesses in order to lower the risk of business covid infection to the lowest possible level at the lowest possible cost and with the highest possible efficiency. Managers and other organizational leaders encountered even more challenges as a result of this. They must succeed based on their own emotions and attitudes, quickly adjust to the new reality, and successfully manage the new organizational reality. Due to the ongoing uncertainty, people's behavior and attitudes have also changed, and their emotional state has elevated. Even while still in paid work, many people have had to reduce their working hours as a result of the pandemic. We will concentrate on a group of firms in an area or a major metropolis, then, we synthesize data, construct models, and provide the most effective solutions for the entire problem from which we give collaboration or non-cooperation strategies, synthesize data, and generate the most effective solutions for the entire problem. A SPEA2 algorithm is also offered for optimizing the optimum approach for each business in the multi-objective decision-making to overcome the situation.

1. Introduction

Suspending all the business works for a long time due to the covid pandemic will cause many enterprises to struggle. However, if businesses go back to work, they will face problems related to the health of each employee, especially the risk of being infected with covid. If an enterprise wants to develop sustainably and stably, they need to have healthy employees who are not infected with Covid. Because in the worst case, just one employee in that company is unfortunately infected, and they will have the ability to spread to other employees. Not only within the company but the infected employees in this company also have the ability to infect employees in other companies. Discussing this conflict, Murat Özkaya and Burhaneddin İzgi [1] analyzed the general or self-quarantine effects to the spread of the first wave of Covid-19 pandemic in the view of the game-theoretical approach, " We first choose three countries such as South Korea for self-quarantine, Italy, and Turkey for general quarantine during the analysis of the different stages of the spread ". When human resources are not available, businesses will fall into a crisis in all aspects. In this article, we try to find the most reasonable solution for businesses to ensure the health and safety of their employees, as well as the business itself. To do this, we will:

- Introducing Game Theory and Nash Equilibrium.
- Proposing the Unified Game-Based model, with the players are: businesses, each business will have a set of strategies to choose from (split into 2 types of cooperation and non-cooperation).

We'll see if each strategy a company adopts is effective, there will be an impact on the health of the employees in the business itself, as well as other businesses in the area. From there, players which are the companies find the Nash Equilibrium that provides a neutral solution to conflicts or a "win-win model among players" to find the set of strategies that are most likely to ensure employee safety with the cheapest cost, shortest time and the least amount of human resources. Finally, the article will be applied experimentally in some cities to show the applicability as well as the objectivity of the article. We will use actual data on the epidemic situation of each city, thereby, assessing the necessity of applying game theory in choosing strategies for sustainable development for businesses. Although each region and each city has different epidemic situations, enterprises should apply the model in the article as a suggestion and reference to come up with the best strategy for themselves. The research paper will be focusing on the SPEA2 algorithm for resolving issues and finding the strategies for enterprises during this period of time. One of the most prominent multi-objective evolutionary algorithms that uses an elitism approach is the modified Strength Pareto Evolutionary Algorithm (SPEA2), " SPEA2 was designed to overcome the aforementioned problems. The overall algorithm ", said by Eckart Zitzler in his research [1]. SPEA2's fitness assignment scheme assigns a raw fitness value to each individual based on the strength value of the solutions that dominate it. Additional density information is used to distinguish between individuals with similar raw fitness scores. SPAEA2 mixes offspring and current population to create the future generation. Following that, the most nondominant and diverse individuals are selected. For the sake of preserving diversity [2].



(a) Pareto boundary for profit and risk

(b) Pareto boundary for three targets

Figure 1: Pareto boundary for investment decision-making.

2. Literature Review

Before delving to the main issue, we took the first look through several papers and articles with the same topic and here are what we collected.

As the author pointed out on “Optimal governance and implementation of vaccination programmes to contain the COVID-19 pandemic” (2021) [3], they emphasize that decision-making under uncertainty and imperfect information, and with only conditionally optimal outcomes, is a unique forte of established game-theoretic modeling, as the author pointed out on ”Optimal governance and implementation of vaccination programmes to contain the COVID-19 pandemic” (2021) [3]. In order to achieve the best framework for modeling and simulating vaccine priority and uptake that will be easily accessible to inform crucial policy decisions for the best control of the COVID-19 pandemic, they might adopt this technique. 2020 (Martin Brüne) [4], They contend that sickness behavior (SB) and the behavioral immune system (BIS) represent two adaptive responses to impending and actual infection, respectively, and that individuals who activate their BIS differ from those who exhibit SB in significant ways that may have implications for the prevention and treatment of COVID-19. Additionally, they recast some of the pandemic-related behavioral health problems in a game-theoretical setting, highlighting the problems that occur when public health is viewed as a ”public good.” According to LR Janjua (2021) [5], among other industries, the tourist industry always plays a crucial role and significantly boosts Thailand’s GDP. The tourism business is seeing a decrease globally as a result of the current pandemic crisis. The purpose of this essay is to use ARIMA forecasting to predict the number of tourists visiting Thailand during the following nine months.

According to Ozigi Emmanuel Enesi [6], his study explicitly highlights how the COVID-19 pandemic has affected the performance of SMEs in Abuja and offers suggestions on how their companies can grow and perform successfully in the face of the pandemic’s many difficulties as well as the faltering national economy. In a different post that was published in April 2020 to help SME’s survive the COVID-19 pandemic, Fika Fitriasari [7] proposed a business model that could be adopted by SME’s utilizing the Business Model Canvas technique (Business Resilience). In contrast, writers in a work titled Digital Strategies and Organizational Performances of SMEs in the Age of Coronavirus [8] explore the essential assumptions about decision-making, organizational change, change management, risk prevention, and knowledge management. These presumptions serve as the cornerstone of an efficient and successful digital transformation strategy.

They contend that for asymmetric countries, the weakest-link game presents both a coordination challenge and a cooperation problem in ”Corona-Pandemic: A Game-Theoretic viewpoint on Regional and Global Governance” article (4 Aug 2020) [9]. Additionally, they employed epidemiological modeling in ”Individually optimal choices can be collectively devastating in COVID-19 disease control” (30 April 2021) [10] to estimate the effects of noncompliance on control of SARS-CoV-2. Their simulations show that disobedience is a Nash equilibrium under a variety of circumstances and that, in the long run, a noncompliant population can lead to widespread endemic disease following a restoration to pre-pandemic social and economic activities. Similar to this, evolutionary game theory and public goods games provide a crucial foundation to comprehend in ”Noncompliance with Safety Guidelines as a Free-Riding Strategy: An Evolutionary Game-Theoretic Approach to Cooperation During the Covid-19 Pandemic” paper (16 March 2021) [11].

According to this viewpoint, the COVID-19 situation can be viewed as a conundrum in which those who disregard safety precautions act as free riders because they get to benefit from the reduction in health risks caused by others' adherence to regulations despite not contributing to or even jeopardizing public safety themselves. Together, they discuss the social dynamics involved in public goods problems concerning the transmission of infectious illness, highlight the benefits and drawbacks of evolutionary game-theoretic methods for managing COVID-19, and offer fresh ideas based on new obstacles to collaboration.

Roma Priya (25 Apr 2020) [12] offered various ideas, including monitoring spending in relation to revenue status, making policies for the following three, nine, or 18 months, and being patient while securing investments. The authors used the prisoner's dilemma to assess the state of business during the COVID pandemic in another work, Coopetition in Quantum Prisoner's Dilemma and COVID-19 [13]. In the study titled Managing small business in Nigeria amid Covid-19 Crisis: Impact and Survival Tactics [14], Olufemi A Adalajebi conducted research on small businesses in Nigeria, the statistics of each business, and how they are affected by the pandemic. Together with Chinese authors, Jinyu Wei, Li Wang, and Xin Yang examined the interaction strategies and evolutionary game analysis of the actions taken by the government and the public in the early stages of the epidemic are incorporated into the natural transmission mechanism model of the epidemic, and then the transmission frequency equations of COVID-19 epidemic.

Generally, these studies mention a lot of approaches for both big and small enterprises to deal with the pandemic. Nevertheless, most of them are business strategies. We are looking for strategies that directly affect the most important part of each company, employees. The number of people in big enterprises possibly reaches one thousand so that is necessary to take care of employees' health and protect them from the virus. In this paper, we did differently and released a set of strategies built by local search, improved by Unified Game-based Model and SPEA2 algorithm.

3. Problem description

SARS-CoV-2, the global contagion, mostly has been transmitted in a variety of settings outside of healthcare facilities in a subtle way. By preserving open and basically safe workplaces, policies targeted at protecting employees particularly help to limit community transmission of the virus and for all intents and purposes protect actually national economies, which mostly is quite significant. It's critical to basically have consistency in actual national and really local recommendations for preventing the virus transmission and protecting workers, or so they definitely thought. According to Equity Growth, Finance and Institutions Southeast Asia [20],far-fetched, 50 percent of small enterprises and more than 40% of bigger businesses must close temporarily or permanently. During the monthly quarantine, however, only approximately 30% of major businesses were forced to close. National and local governments must specifically alter these action items in accordance with e WHO guidance on adjusting for all intents and purposes public health and for all intents and purposes social measures [16] and ILO guidance on occupational safety and health measures to basically reduce the transmission of the disease[17], or so they mostly thought.

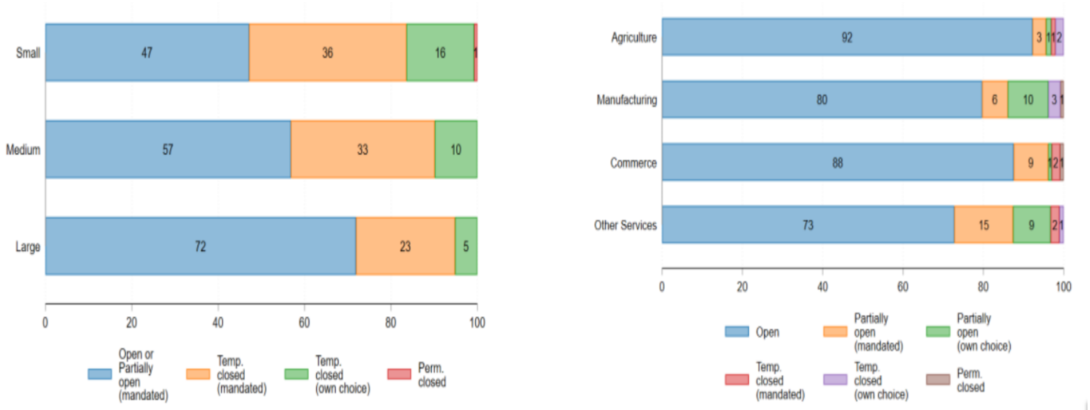


Figure 2: Sales of more than 4/5 businesses decreased in the blockade period

Mechanisms of pandemic impact on enterprises:

Impact	**Description**
Crisis of Demand	About two-thirds of businesses experience a decrease in sales [20]. Sales of some businesses improved, while others declined exspecially small business
Reduce human resources	Although layoffs have decreased slightly, the overall employment situation has not improved significantly. About 10% of businesses are still have to lay off workers
Business Activities	Although most businesses have reopened, many are still functioning at a reduced capacity. About a quarter of businesses still have to cut working hours [20].
Demand and the market output	Demand dropped, owing to a drop in new orders. The main reason for demand reduction is a decline in orders. Late payments and order cancellations are also a problem for firms, but the main reason remains the drop in new purchases.
Supply and the market input	About 40% of businesses face difficulties due to reduced input supply, and 10% have to cancel sales contracts due to insufficient input materials [20].
Approach credit and debit	Access to finance, which is a serious problem in Vietnam, is getting worse especially when the business is facing liquidity difficulties at the same time. Over 60% of sales Businesses said they had difficulty accessing financial resources.[19].

Table 1. Problem description

<Example>
Workplaces with frequent travel, sharing work spaces, poor ventilation, communal eat-

ing areas, and physical person-to-person contact are more likely to report COVID-19 outbreaks [18]. The evidence supports the WHO and ILO's recommendations for COVID-19 prevention, including the use of personal protective equipment (PPE) and remote work directives, limiting access to key employees only, physical separation, routine screening, isolation of infected individuals, contact tracing and quarantining of contacts, regular worksite disinfection (especially of high touch surfaces), hand hygiene, and environmental monitoring.

3.1. Characteristics

The behaviors of enterprises are changing during this time.

- Remote operation has become an indispensable feature of businesses in the pandemic. 100% Businesses deploying online operating models [19].

- Speeding up production to match demand is also a top priority for businesses in Vietnam because businesses that depend on imports are affected, this rate is different between enterprises . Large companies boost their production since the beginning while the small and medium are struggling in finding investment sources.

- Enterprises have avoided layoffs by applying measures such as reducing labor costs, hours and/or wages, and adoption of digital platforms in response to negative economic shocks. However, the short-term adjustments This may be incomplete as the pandemic continues to affect the global economy.

- The financial issue becomes more crucial than ever, the funding is decreasing significantly while the supply still has to be ensured. However, the financial problem could be solved through the investors or their own client investment.

Properties	Characteristics
players (enterprises)	• Has certain financial resources • Choose the working model optimization • Speed up production • Has their own set of clients • Apply digital platform
Strategies	Small and medium enterprises • payoff: business valuation • Winning: The cooperative (profit > risk) • Risk : running out of budget • profit: sales value Large enterprises • payoff: business valuation • Winning: The cooperative (profit > risk) • Risk : investors unavailable • profit: sales value

Table 2. Summarized characteristics

3.2. Example with sampled data set

The use of the ant colony algorithm is discussed using a specific investment strategy as a case study. An organization needs to make the following investments in four development firms during the course of the three-year planning period :

2*Investment plan (3 years)	Small	Medium		Big
	A	B	C	D
investment ($)	10.000/year	150.000 (begin in 3rd year)	100.000 (begin in 2nd year)	200.000
Speeding up Production	remain the same	promote 10%	promote 20%	promote 30%
expected profit	20.000 each year	4.000 for every 10.000	6.000 for every 10.000	5.000 for every 10.000

Data set (i)

- Investments in Company A are welcome from the first to the third year. Every 10,000 dollars invested is expected to yield a profit of 2,000 from the investment projects, and both the annual capital and the profits from that year can be reinvested in the investment plan.
- Investment in Company B is required at the start of the first year. After two years of investment, it can generate a profit of 5,000 dollars for every 10,000 spent, with a 30% increase in output rate, which can then be reinvested back into the investment plan. However, the project's total investment should not exceed 200,000.
- whereas Company C requires investment at the start of the second year. After two years, every 10,000 invested can generate a profit of 6,000 per year, with a 20% rise in production rate, however the total investment for this business should not exceed 100,000 dollars.
- Company D has to be invested in the third year, with a profit of 4,000 for every 10,000 invested, increasing production by 10%, although the total investment for the project is only 150,000. The maximum investment that the business can make during the planning period is 300,000 dollars.

year	A	B	C	D
1	16.52	13.47		
2	7.27		11.89	
3	19.66			3.33

Table 3. Investment strategy (profit and risk are considered)

The relationship between profit and risk is practically linear when the risk is less than 8, but it will increase when the profit is larger than 16. Decision-makers can use this conclusion as data support so they can optimize profits based on their tolerance for risk. The investment strategy in Table 3 solely takes profit into account. An investment plan that takes into account both profit and risk is shown in Table 3. The investment plan shown in Table 3 has a total profit of 275,000 dollars. However, when risk is factored in, the investment strategy's risk is 22.24. The investment plan in the table above takes into account both profit and risk. The investing plan makes a total profit of 23.88, but the risk is cut in half to 15.64. The profit under Table 3's investing approach is just 13.16% lower than it is in Table 3, but the risk is decreased by 29.68%. According to the aforementioned findings, firms should prioritize limiting investment risks while also maximizing profits.

Which type of investment plan will enable the business to achieve the greatest profit during the entire investment plan is the problem that needs to be answered. Every investment will, however, carry some risk. When making an investment, businesses always aim for the lowest risk. For each investment, the risk parameters are R= [0.1, 0.25, 0.5, 0.75]. Enterprises also anticipate that the environmental cost of their investments will be as minimal as possible. E= [0.15, 0.3, 0.2, 0.4] are the environmental cost coefficients in this instance. This issue is resolved using the suggested approach. The initial population size is 300, the external archive size is 50, the crossover probability is 0.6, and the mutation probability is 0.3. These are the model's parameters. We simply take into account investment profit and risk-optimization objectives.

The key to archiving the reward for every enterprise is, in general, picking an investment strategy. We must understand the unit profit, investment risk, and investment environment consumption for the investment optimization problem covered in this study. The annual investment amount for various investment products is the best outcome found in this article. Of fact, various restrictions on investment optimization are possible. This document offers a general approach to dealing with these investment issues.

4. Model

4.1. Introduction to Unified Game-Based model

Game-based learning (GBL) is when specific gaming elements are borrowed and used in real-life situations to engage people or any kind of object. We may connect with instructional materials in a creative and dynamic way because of the motivating psychology inherent in game-based learning.

GBL employs competitive activities to push us to study better by putting them against one other or challenging them to challenge themselves. Games with a fantasy theme sometimes include players in a learning activity via a plot.

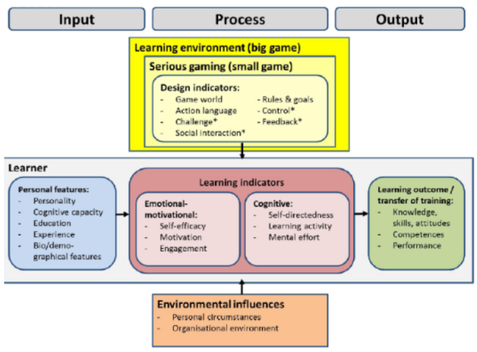


Figure 3: The game-based learning evaluation model (GEM)

The Unified Game-based model is represented as follows [23]:

$$G = (\{P_0, P\}, \{S_0, S_i\}, \{u_0, u_i\}, R^c) \tag{1}$$

Where:

- G : Unified Game-Based model
- P_0 : special player, this player will represent the project, this player will represent the benefit of the entire project when compared to other casual players
- S_0 : denotes the strategy set of special player $\{S_{01}, ..., S_{0j}, ..., S_{0M_0}\}$ where M_0 is the number of strategies of P_0
- U_0 : the payoff function of P_0 references a particular player's strategy to real numbers
- N : number of normal players
- P : a set of players (in our case are enterprises)
- S_i : a set of strategies of player i ($1 \leq i \leq N$) $\{S_{i1}, ..., S_{ij}, ..., S_{iM_i}\}$ where M_i is the number of strategy of player i.
- U_i : the payoff function of player i references a particular player's strategy to real numbers.
- R^c : is a vector space representing the set C of problems.

The Nash equilibrium of the model is determined as follows [19]:
When player i ($1 \leq i \leq N$) choose the strategy $s_i \epsilon S_i$ and S_{-i} is the strategy of other players. The U_i of payer i is $U_i\left(s_i, s_{-i}\right)$ and the set of strategies $S^* = \left(s_1^*, ..., s_j^*, ..., s_N^*\right)$. The Nash equilibrium happen when $\left(s_i^*, s_j^*\right) \epsilon S^*, \left(s_i^*, s_j^*\right) R^c, (1 \leq i, j \leq N)$ and $u_i\left(s_i^*, s_j^*\right) \geq u_i\left(s_i, s_j^*\right) \vee s_i \epsilon S_i$

The use of the Nash equilibrium formula in this field is significant since it aids a company in determining the greatest payout in a circumstance based on not only their own actions but also the decisions of other parties involved. Nash equilibrium may be used in a variety of situations, including commercial strategy, home sales, combat, and social sciences.

In this work, we used a Unified Game-based model to develop a novel approach that addresses the aforementioned difficulties by including conflict information and additional activity characteristics into the model.

4.2. Mathematical Approach

Mathematical optimization issues containing many objectives are the focus of multi-objective optimization, sometimes referred to as multi-objective programming, vector optimization, multicriteria optimization, multi attribute optimization, or Pareto optimization. The issue will be resolved via multi-objective optimization and is defined as follows in [19]:

$$minF(X) = (f_1(X), f_2(X), ..., f_m(X)) \tag{2}$$

$$\text{s.t. } g_1(X) \leq 0, i = 1, 2, ..., p$$

$$h_j = 0, j = 1, 2, ..., p$$

Where $X = [x_1, x_2, ..., x_n]$ is the decision variables. The optimization objection is fi. One of the key ideas in multi-objective optimization is Pareto domination. The following are the ideas of Pareto domination and Pareto solution set:

- **Pareto dominance** : If there are two individuals in an evolutionary population named A and B, and A dominates B $(A\phi B)$
- **Pareto-optimal set** : The Pareto optimal solution set P^* is the collection of all Pareto-optimal answers, and it is defined as follows:

$$P^* = \{X^* | \dashv \exists X \epsilon X_f : X \phi X^*\} \tag{3}$$

Investment choices with a profit motive can be described as follows in the conventional sense. A company's yearly investment budget for a one n year plan period is $b_i, (i = 1, 2, .., n)$ and it can invest in a variety of projects. The profit $I_{ij}(j = 1, 2, ..., n)$ per unit investment project in the year i is called as d_{ij}. The aim is to maximize overall profit over the specified time period. However, profit-driven single-objective decisions frequently overlook the complexity of investing. An investment is frequently assessed from a variety of perspectives, including investment profits, investment risks, and project environmental costs. Environmental cost (EC) is defined in economics as the energy consumption equivalent to investment [19].

$$Profit = \sum_i \sum_j d_{ij} I_{ij} \tag{4}$$

$$Risk = \sum_i \sum_j d_{ij} I_{ij}, EC = \sum_i \sum_j E_i d_{ij} I_{ij} \tag{5}$$

Among these, the sum of investment made in I_{ij} year should not go over the amount budgeted for investments in the i year, nor should the investment amount be negative. The aforementioned model is a generic investment planning model that may be applied to other economic activities and only slightly adjusted in practice (such as: selection of construction projects, utilization of foreign capital). This is an issue of figuring out

Year	Plans					
	1	2	$\cdots$	j	$\cdots$	m
1	I_{11}	I_{12}	$\cdots$	I_{1j}	$\cdots$	I_{1m}
2	I_{21}	I_{22}	$\cdots$	I_{2j}	$\cdots$	I_{2m}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
i	I_{i1}	I_{i2}	$\cdots$	I_{ij}	$\cdots$	I_{im}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
n	I_{n1}	I_{n2}	$\cdots$	I_{nj}	$\cdots$	I_{nm}
Risk	R_1	R_2	$\cdots$	R_j	$\cdots$	R_m
EC	E_1	E_2	$\cdots$	E_j	$\cdots$	E_m

Figure 4: Description of investment parameters [19]

the best investing strategy. This investment plan can be satisfied in a variety of ways. Due to the limits of varied investing situations, finding the best investment plan using generic approaches is challenging. The optimization goal may be stated as follows [19]:

max Profit = $0.2I_{1A} + 0.2I_{2A} + 0.2I_{3A} + 0.5I_{1B} + 0.6I_{2C} + 0.4I_{2D}$
min Risk = $0.a(0.2I_{1A} + 0.2I_{2A} + 0.2I_{3A}) + 0.25I_{1B} + 0.5I_{2C} + 0.75I_{2D}$
min EC = $0.15(0.2I_{1A} + 0.2I_{2A} + 0.2I_{3A}) + 0.3 + 0.5I_{1B} + 0.2 + 0.56I_{2C} + 0.4I_{2D}$

4.3 Nash Equilibria formula and its applications in the field

A list of player actions that each player feels is the optimal response to the other players' actions is known as a Nash equilibrium. In this discipline, the decision-making process for choosing an investment strategy is one of the most well-known uses of NE.
Each player's approach in the Nash equilibrium is the best one given what the other players have decided. Because everyone receives the result they want, everyone wins.

A model in the formula defines a game with n players :

$$u_i(s_i^*, s_i^*) \geq u_i(s_i, s_i^*) \forall s_i \epsilon S_i \tag{6}$$

In a game, there may be more than one Nash equilibrium. Even though the equilibrium is distinct, it might not be strong enough because a player might be undecided given the actions of the other players. If the inequality is strict, the equilibrium is known as a stringent Nash equilibrium, and the following approach is the best one to use:

$$u_i(s_i^*, s_i^*) \geq u_i(s_i, s_i^*) \forall s_i \epsilon S_i, s_i \neq S_i^* \tag{7}$$

The strategies set S_i of each player is different. Although the notion of Nash equilibrium does not entail a limited number of strategies, the existence proofs of Nash do. A third-person viewpoint can sometimes make the Nash equilibrium seem illogical. This is due to the fact that a Nash equilibrium is not always the Pareto ideal state [22].
In the competition game, Nash Equilibria is most notably used as a tool within the study of business and economics.

4.4. Nash Equilibria using Nikaido Isoda function

In 1955, When the generalization of the Nash equilibrium problem in a non-cooperative game , H. Nikaido and K. Isoda introduced an equation [21]:

$$f(x^*, x) = \sum_{i=1}^{n} (f_i(x) - f_i(x[y_i])) \tag{8}$$

Nikaido-Isoda function defines the Nash equilibrium of the conflict problem in project management. Where vector $x[y_i]$ is the vector obtained by vector x replaced $x_i by y_i$ and the K_i is the strategy set of player i. The tactic of the game is $K := K_1 \times ... \times K_n$, so the $x^* \epsilon K$ is the Nash Equilibria point of the game. That mean finding Nash Equilibria is finding $f_i(x)$
In the unified game-based model, the nash equilibria is the definition of $u_i(s_i^*, s_j^*)$ in

which the tactic set $x^* = S^* = (S_1^*, ..., S_j^*, ..., S_N^*)$[21]. So we apply the Nikaido function in the game-based model to find the value of $f(x^*, x)$ where x^* is the nash equilibria that we need to find in the game.
Therefores, using the Nikaido Isoda function is the solution for solving the problem of general equilibrium as well as Nash equilibrium. In practice, the Nash equilibria need to satisfy additional constraints and the calculation to find the Nash equilibria depends on the dataset and the given data of the game. However, the function is the optimal solution in multi-object decisions by multi-objective evolutionary optimization algorithms.

5. Algorithm with Nash Equilibria

SPEA2, a productive multi-objective optimization genetic algorithm, was introduced by Zitzler et al. [1]. Based on the idea of Pareto domination for fitness allocation and selection processes, it uses the niche technique and an external archiving elite retention mechanism.

The SPE2 algorithm is well-known as multi-objective optimization; in our situation, each enterprise represents an object in the algorithm.Faced with the high complexity of the investment decision-making space, traditional multi-objective optimization methods place too much emphasis on global search ability in order to achieve faster convergence and avoid settling into a local optimum since this makes it difficult to converge to the Pareto optimal border [19]. An improved SPEA2 algorithm is proposed to maximize multi-objective investment decision-making in order to address this issue.

About the SPEA2 algorithm algorithm, the Strength Pareto Evolutionary Algorithm(SPEA2) is an elitist multi-objective evolutionary algorithm. It is also one of the benchmark multi-object EC techniques.

- SPEA2 incorporates a fine-grained fitness assignment strategy having the complexity of order $0(Q^2), whereQ = N + N$
- A density estimation technique having the computational complexity of $0(Q^2)$ and an enhanced archive truncation method having the complexity of order $0(Q^3)$

Apply the SPEA2 algorithm for above example (i) to solving the investment strategy

year	A	B	C	D
1	13.6	2.41		
2	3.17		8.45	
3	18.1			0.148

tabe 4. Investment strategy

Profit, risk, and environmental costs in Table 3 are 13.256, 7.529, and 3.252, while they are 13.304, 8.31, and 2.245 in Table 4. The overall profit from the two investment strategies is equivalent, but Table 4's investment risk is 10.36% more than Table 3's, and Table 4's EC is 44.9% higher than Table 4. This highlights the significance of utilizing an optimization model in this research and how the investment technique selected has a big impact on the outcomes. For multi-objective optimization, With a final

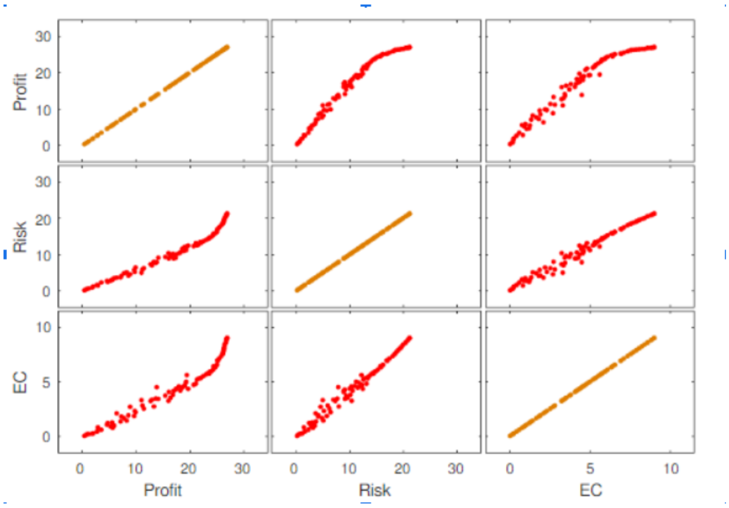


Figure 5: The description of the SPEA2 algorithm

C(P)value of less than 0.008, the updated SPEA2 algorithm can reach the optimum Pareto border in only 15 steps. However, the SPEA2 techniques require more than 20 steps to approach the Pareto boundary, and the final C(P)value is always greater than 0.025. The findings show that due to the algorithm's poor local searchability, traditional SPEA2 techniques struggle to reach the Pareto border. This demonstrates that the choice of investment strategy has a significant impact on the outcomes, demonstrating the importance of the optimization mode.

5.1. Using SPEA2 to find Nash equilibria

- For every solution $i \epsilon Q(t)$, the the strength, $S(i)$ is calculated that represents the number of solutions it dominates, that is:

$$S(i) = |i, j \epsilon Q(t) \Lambda i > j| \quad (9)$$

- Raw fitness of solution (i) is calculated as:

$$R(i) = \sum_{j \epsilon Q(t), i > j} S(i) \quad (10)$$

Meaning, the summation of strength of solutions dominating solution(i) $R(i) = 0$ means individual is a non-dominated solution. Higher value of $R(i)$ means it is dominated by many solutions

Consider a game of n players. Each player takes an individual action, which is represented by a vector x_i in the Euclidean space R^{M_i}. All players take a collective action $x = (x_1, ..., x_n) \epsilon R^{M_i}$ let $X_i \subseteq R^{M_i}$ be an action set of player i and $\phi i : X_i - > R$ be the corresponding payoff function. Let X be the collective action set. By definition, $X \subseteq X_i \sqcap ... \sqcap X_n \subseteq R^{M_1} \sqcap ... \sqcap R^{M_n} = R^m$. Let $x = (x_1, ..., x_n)$ and $y = (y_1, ..., y_n)$ be elements of the collective action set $X_1, ..., X_n$. An element $(y_i|, x) \equiv (x_1, ..., x_{i-1}, y_i, x_{i+1}, ..., x_n)$ of the collective action set is interpreted as a collection of actions when the i-th player tries yi, while the remaining players still keep $x_i, j = 1, ..., i-1, i+1, ..., n$

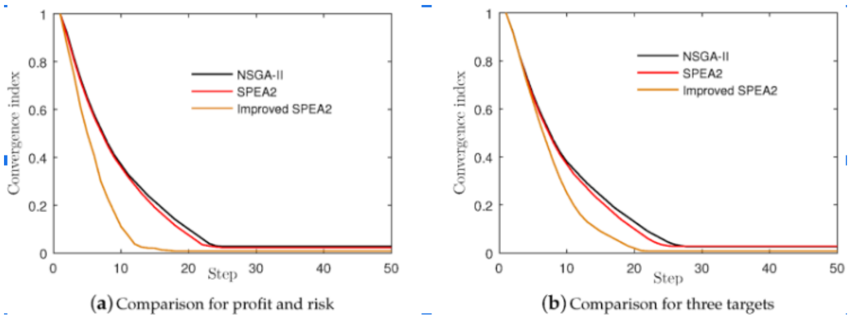


Figure 6: comparision for profit and risk between algorithms

The Nash equilibria will be defined a point : $x^* = (x_1^*, ..., x_n^*)$ is called the Nash Equilibrium point for each i.
In addition to the payoff functions, each player's action spaces may be influenced by the actions taken by the other players.

$$c_{eq,r}(x) = 0(r = 1, ..., N_e q) \quad (11)$$

The generalized Nash Equilibrium problem is the name for this type of problem. A collection of equality constraints is used to express the interdependence of distinct actors' activities. An improved version of the Strength Pareto Evolutionary Algorithm is the Strength Pareto Evolutionary Algorithm 2 (SPEA2) (SPEA). SPEA2 employs a fine-grained fitness assignment method that incorporates density data as opposed to SPEA. The archive is filled with dominated individuals when the number of nondominated individuals is less than the chosen archive size. The original SPEA's clustering mechanism is also replaced with an alternate truncation method that does not lose boundary points, guaranteeing that the boundary solution is kept. Finally, SPEA2 restricts participation in the mating selection process to archive members only. The SPEA2 operates in the manner listed below. The procedure of the SPEA2 is as follows:

input

- Ne : population size
- N : Archive size
- T : maximum number of generations

Output : NDS: non-dominated set.

Process	Action
step 1 (initialization)	Generate the population $P(0)$ and create an empty archive (external archive) $A(0)$ .Set t=0
Step 2 (fitness assignment).	Determine the fitness levels of people in $P(t)$ and $A(t)$
Step 3 (environment selection)	Copy each non-dominant person in $P(t)$ and $A(t)$ to $A(t+1)$. If size of $A(t+1)$ exceeds N then reduce $A(t+1)$ using the truncation operator, unless the size of $A(t+1)$ is less than N the fill $A(t+1)$ with dominated individuals in $P(t)$ and $A(t)$
Step 4 (termination)	if t>T is reached, it terminates and outputs NDS. Otherwise, keep going.
Step 5 (mating selection)	Choose a winner in a binary tournament using replacement on $A(t+1)$to make the mating pool full. The mating pool's size is Ne
Step 6 (reproduction)	To the mating pool, apply the recombination and mutation operators $A(t+$ to the resulting population. Set $t=t+1$; go to step 2.

Table 5. Process of SPEA2 execution

```
Input: N: population size, N: archive size, T: maximum number of
generations, t = 0
Generate an initial population P(0) and create the empty archive Ā
(0) = 0
Calculate fitness of solutions in P(t) using the fine-grained
fitness assignment strategy and copy A(t)
while (t ≤ T) do
      M(t): Binary tournament selection with replacement (Ā(t))
      P(t + 1): Crossover and mutation operators (M(t))
      Calculate fitness of solutions of C(t + 1) = P(t + 1) ∪ Ā(t)
      using the fine-grained fitness assignment strategy
      Find the number of non-dominated solutions (N_NS) in C(t + 1);
      if (N_NDS = N̄) then
      Copy all non-dominated solutions to Ā(t+1)
      else if (N_NDS < N̄) then
      Copy all non-dominated solution to Ā(t+1) and the donated
      solutions from C(t + 1) using the fitness till the archive is
      full
      else
      Eliminate non-dominated solutions one by one using the
      truncation operator till the archive is full
      end if
      t = t + 1
end while
```

Figure 7: SPEA2 pseudo code

SPEA2 pseudo code

SPEA2 Algorithm has been modified to become AOSPEA Algorithm. Based on the aforementioned descriptions of the simulated binary crossover, polynomial mutation, and differential evolution operator, SPEA2, and adaptive selection of evolutionary operators' scheme, an improved SPEA2 algorithm with adaptive selection of evolutionary operators scheme (AOSPEA) is presented.

The input and output from SPEA2 are essentially the same. The finite population basis of evolutionary algorithms prevents them from achieving all Pareto solutions for multi-objective optimization with infinite optimal Pareto replies. In order to spread the ideal Pareto set as widely and equally as feasible, multiobjective optimization algorithms aim to gain a piece of it. We demonstrate, by use of a finite Markov chain, that the AOSPEA algorithm asymptotically converges to the ideal Pareto set with probability 1.

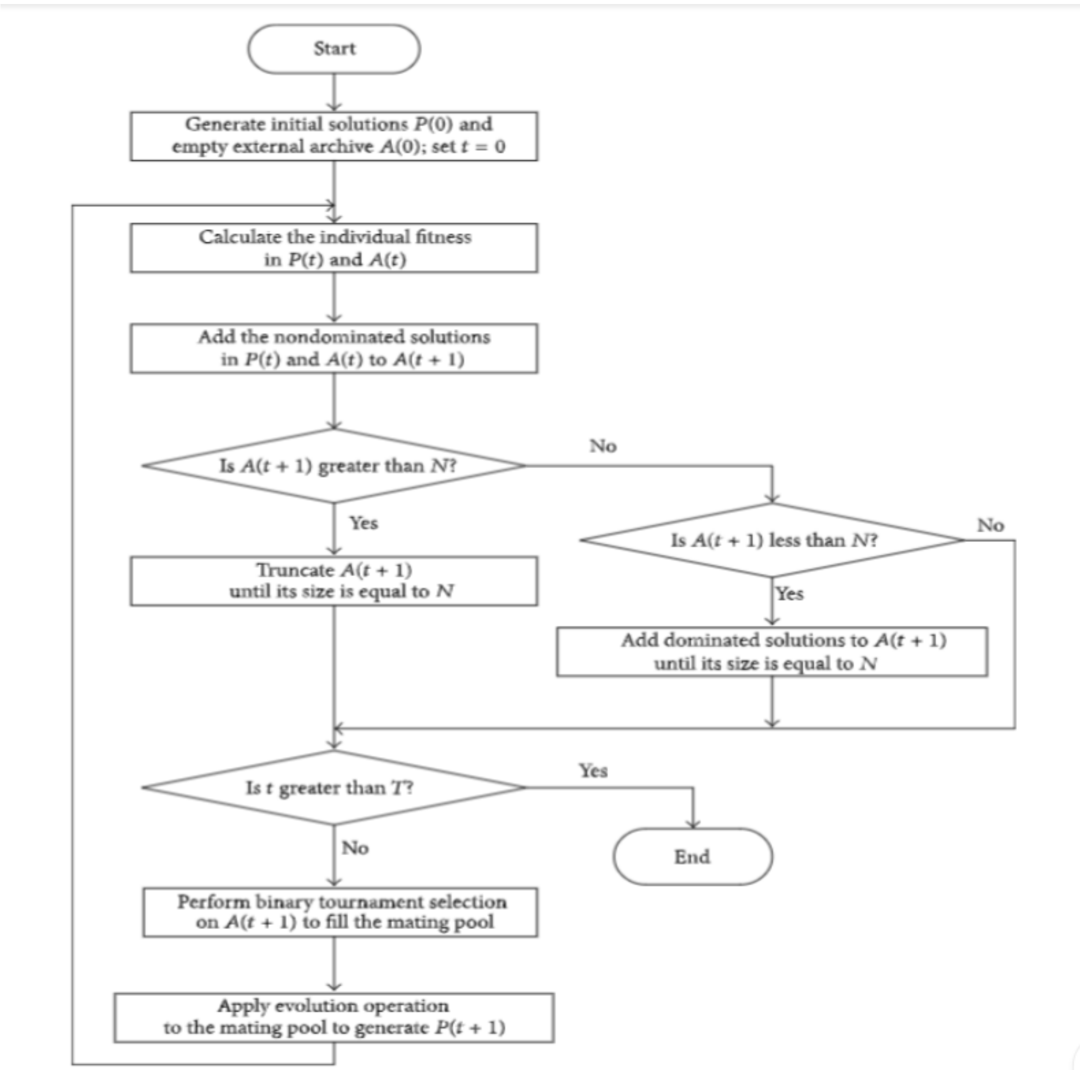


Figure 8: AOSPEA pseudo code

Definition 1. S is a finite set and a random sequence $X_t, t = 0, 1, 2, ..., n$ is from S and if all $t \geq 0, i, j$ belong to $S \times S$,there will be Nash Equilibrium point for each t [21].

$$P\{X_{t=1}X_t = i, X_{t-1} = i_{t-1}, X_0 = i_0\} = P\{X_{t=1}X_t = i\} = P_{ij} \tag{12}$$

Definition 2. let $T_m : S^n - > S$, where denotes the mutation in the DE operator and is followed by the probability distribution

$$P\left(T_m(x) = V_i)\right) = \sum_{x_{r1}, x_{r2}, x_{r3} \epsilon S^3} P(T_m^1(X) = \{x_{r1}, x_{r2}, x_{r3}, F\}) \tag{13}$$

Definition 3. let $T_{SBX} : S^n - > S$ as SBX crossover, and the following equation can be used to define its probability distribution:

$$P\left(T_{SBX}(X, \beta) = y_i\right) = \sum_{x_{r1}, x_{r2} \epsilon S^2} P(T_{SBX}(X)) = \{x_{r1}, x_{r2}\} \times \beta \tag{14}$$

Definition 4. let $T_{PM} : S^n - > S$ PM crossover is denoted, and its probability distribution is given by:

$$P\left(T_{PM}(x_i, X_{i,UB} \supset X_{i,LB}, \delta]\right) = Y_i) = \delta \tag{15}$$

AOSPEA's evolution can be characterized as $X_t \xrightarrow{b} X_{i+1}$; that is $X_{t+1} = X_t \times P = X_t \times M_{SBX} \times M_{PM} \times M_{DE}$ the population sequence's transition matrix $P = M_{SBX} \times M_{PM} \times M_{DE}$ where there exist $P(T_m(X) = v_i > 0).M_{SBX}, M_{PM}, M_{DE}$ are positive transition matrix. Therefore, P is a positive matrix . Therefore, the population sequence $X_t, t = 0, 1, 2, ...$ A Nash equilibrium has always existed in the equation, therefore the AOSPEA method is gradually solving it. equation.

6. Conclusion

We introduced the application of Game Theory to choose strategy for enterprises in Covid19 pandemic situation in this research, as well as how to establish its Nash Equilibrium using SPEA2 algorithm. This paper introduces basics in Game Theory and Nash equilibrium, SPEA2 algorithm and helps to understand the importance of choosing a strategy for businesses during the Covid pandemic. We also found similar studies with the selected topic, evaluated and proposed an improved modeling solution for multi-objective decision-making in enterprise against the pandemic. This paper has some limitations that need to be considered when researching. Therefore, the model proposed and tested in this study requires further testing to discover and build a more precise and specific general model. Due to limited knowledge, the research problem of "Game Theory to choose strategy for enterprises in Covid19 pandemic situation using SPEA2 algorithm" within the framework of this paper only stops at initial studies. We will continue to improve the model with higher applicability to the problem.

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