ISSN 1822-8011 (print)
ISSN 1822-8038 (online)
INTELEKTINĖ EKONOMIKA
INTELLECTUAL ECONOMICS
2010, No. 2(8), p. 47–56

STRATEGIC DECISION-MAKING AND GAME THEORETIC APPROACH FOR THE COMMERCIALIZATION OF NANOTECHNOLOGY

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Abstract. Game theory cannot be implemented successfully until practical models and the platform on which it can be simulated are explored. The applications of the game theory for various technical problems are introduced and a model for nanotechnology is developed. Recent applications of nanotechnology are considered for model development, with a focus on its application in companies wishing to implement nanotechnology in their future products. The implementation of such models is met by an HPC setup which is used for the developed game theory-based computations for the commercialization of nanotechnology. A classical game is defined depending on various parameters required to predict the rate of commercialization of a nano device. The rate of commercialization is developed and the gaming model is modelled with reference to the commercialization theory. Equilibrium cases pertaining to business in nano domains are studied and a proposal on the impact of various strategic profiles with the payoff is computed. This study is applicable in the study of nanotech wars which may resort to extensive use of nano materials. It can also be used for the estimation of time taken for the commercialization of a nano device. The strategy of a company for the commercialization and implementation of a novel nano device can be affected by other companies' efforts to do the same; therefore, the need of strategic decision-making emerges. In such strategic conditions, the model may assists companies in their decision-making. In this case, the modelling complexity increases; this aspect has been addressed and the modelling was simplified seeking for a better understanding of the phenomenon.

JEL Clasification: C600+C680, C790, C 890.
Keywords: game theory, HPC (High Performance Computing), business, nanotechnology.
Reikšminiai žodžiai: lošimų teorija, ypač tikslūs skaiciavimai, verslas, nanotechnologija.`

Introduction

Game theory is a branch of applied mathematics. It was originally formed to give answers to complex problems of economics, but with its advancement it became a widely applied field such that it could be applied in computer science, politics, international relations and every other field. It can simply be seen as a multiplayer game approach in which the success of any of the players depends on the approach taken by the others. The most logical direction in the game theory is to find the equilibria in the game. Equilibria can be explained as the strategy adopted by each player which they are unlikely to change throughout the game. Though many equilibrium concepts are developed over time, the one worth noting is the Nash equilibrium concept developed by John Nash. If each player has chosen a strategy and no player can benefit by changing his or her strategy, while the other players keep their strategy unchanged, then the current set of strategy choices and the corresponding payoffs constitute a Nash equilibrium.

The Nash equilibrium concept is used to analyse the outcome of the strategic interaction of several decision makers.

In other words, it is a way of predicting what will happen if several people or several institutions are making decisions at the same time, and if the decision of each one depends on the decisions of the others.

The forms in the game theory can be of many types, but two most widely used forms are:

- extensive form;
- normal form.

In the extensive form, the player who plays second knows the move of the first player and, therefore, the second player can change the move accordingly to the move of the first.

On the other hand, the normal form is a more fair approach in which both players make their moves independently without being influenced by the moves of each other. Game theory has come to play an increasingly important role in logic and in computer science. In addition, computer scientists have used games to model interactive computations.

The emergence of the Internet has fostered the development of algorithms for finding equilibria in games, markets, computational auctions and security and information markets. Game theory has been applied in many areas. When a company uses a nano device in enhancing the quality of its production, other companies are bound to work on the commercial model and incorporate the changes into their framework.

1. Current Scenarios and Analysis of the State Of Art Technology

The Nash equilibrium has been researched extensively in recent years. We know that when players select their actions randomly, there is a guaranteed existence of the Nash equilibrium called the mixed framework, but in many real world problems the existence of an equilibrium is not enough. In some situations, it is often desirable to remove equilibria for additional requirements such as to guarantee a minimum payoff to certain players, and this situation is called a constrained Nash equilibria. A thorough study of the constrained Nash equilibria was performed by Greco and Scarcello (2009). A polynomial-time Nash equilibrium algorithm for an average-payoff was developed by Littman and Stone (2004). The algorithm is for an average-payoff.

The Nash equilibrium can be called pure, if each user is settled by choosing a single link; on the other hand, it is fully mixed, if each user chooses every link with non-zero probability. To evaluate the Nash equilibria, Gairing et al. (2008) formulated the social cost as the sum of the users' individual costs. The social cost of any Nash equilibrium is not more than the social cost of the mixed Nash equilibrium that may exist only uniquely for the case of identical users. A method for the characterization of the Markov perfect Nash equilibria being Pareto efficient in nonlinear differential games was developed by Martín-Herrán and Rincón-Zapatero (2004). A new method was applied for the computation of the Nash equilibria with Markov strategies using a system of quasilinear partial differential equations.

When more than two suppliers are competing for the same order, there is a question of equilibria. Methods to compute the equilibria of this model were developed by Saiz and Hendrix (2007).

The most challenging task of a game model is to detect its Nash equilibria. Three computational intelligence techniques were studied by Pavlidis et al. (2004). The three methods are covariance matrix adaption evolution strategies, particle swarm optimization and differential evolution. The model proposed in the present paper can be expanded by these theorems. An algorithm for computing a % - Nash equilibrium for any bimatrix game in a strongly polynomial time was suggested by Bonifaci et al. (2008). The complexity of finding Nash equilibria in which the strategy of each player is uniform on its support set was studied by Kontogiannis et al. (2008). The set of Nash equilibria strategy profiles of every finite non-cooperative game in normal form coincides with the supercore of its associated abstract system, since under a binary relation that refines the standard relation which only accounts for single profitable deviations (Inarra et al., 2009). In this paper, a model of nanotechnology for Nash equilibrium is introduced and explored in detail; the model can be applied to other advanced models that are proposed.

There have been many proposals on the application of the Nash equilibrium in recent years. The public transport system can be portrayed as a special commodity market where a passenger is the consumer, a transit operator is the producer and the special goods are the service for the passenger's trip (Sun and Gao, 2006). In this model, the Nash equilibrium game is applied by to describe how passengers adjust their route choices and trip modes (Ibid.).

Also proposals for including the Nash equilibrium into security and wireless applications have been made in recent years. Considering a network that can be anytime infected by a virus attack, the system security software can be applied to a limited part of the network only. Mavronicolas et al. (2005)

implemented this practical model by making a Path and Edge Model in which two kinds of players work: one is the attacker and the other is the protector. This is a non-cooperative multi-player game on a graph associated with the Nash equilibria. Internet and the WWW may also be made more secure using the Nash equilibrium. Immorlica et al. (2006) studied the problems faced while designing the hyperlink structure between the web pages of a particular website to maximize the revenue which is generated by the traffic associated with the website.

Nanotechnology will have its effect on Wireless Sensor Networks (WSN), which we explored in one of our recent works, from where we got the motivation to develop a game theory model to facilitate the implementation of nanotechnology (Kukushkin, 1997). A cooperative game theory was used to improve the performance of WSNs by Zhao et al. (2008). Each player estimates the state of the game, then the player adjusts its local parameters. According to the results generated, the key problem faced by WSNs is the way of designing an apt equilibrium strategy based on the various conditions of the game. Simulation results obtained by Zhao et al. (2008) showed that an incompletely cooperative game is a good tool to improve performance, decrease delay and packet-loss-rate. A review of the game theory with regard to the experience gained from the programming automated agents within Advance Decision Environment for Process Tasks (ADEPT) project was performed by Binmore and Vulkan (1999). A new general hierarchical Grid computing model taking into account machine selfishness was presented by (Kwok et al., 2005).

Table 1. Categories of non-cooperative games and their main research areas (Xiao et al., 2005)

	Static Game	Dynamic Game
Complete information game	Complete information static game, Nash equilibrium (Nash, 1950; 1951)	Complete information dynamic games, Subgame perfect Nash equilibrium (1965)
Incomplete information game	Incomplete information static game, Bayesian Nash equilibrium (Harsani, 1967-1968)	Incomplete information dynamic games, Perfect Bayesian Nash equilibrium (Selten,1975)

The applications are also used to develop protocols and standards. In the study of Xiao et al. (2005), a game theoretic model was demonstrated to construe an IEEE 802.11 distributed coordination function mechanism. The major technique is fast emerging for the optimal control of nonlinear systems called Reinforced Learning (RL).

Sharma and Gopal (2010) took a new approach: Markov games as an alternative system model to enhance the generality and robustness of the RL-based approaches were dealt with. Employee Stock Options (ESO) were analyzed, the effects of ESO on employee performance were studied and the transactions of ESO were explained using a game theory model by Nwogugu (2006).

In the field of economics, Herbert Simon is known for his harsh criticism of the rationality postulate. The response of Herbert Simon to the development of the game theory was studied by Sent (2004). New theories of financial contracting were introduced and analyzed by Nwogugu (2007). Future oil prices were analyzed and a game theoretic setting for decision-making under the conditions of uncertainty and risks was developed by Reneke (2009).

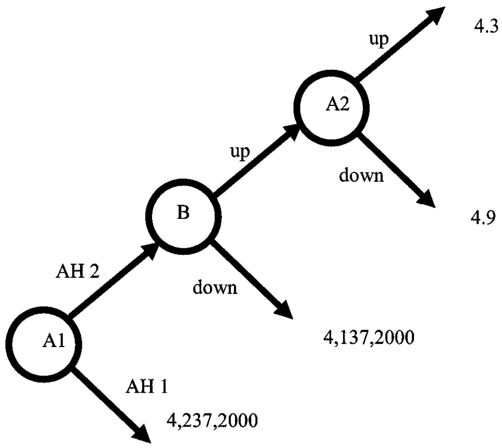

Figure 1. **Two-person extensive-form game (Mccain, 2009)**

Mccain (2009) performed a theoretical and experimental study of the game theory to draw a conclusion that the motivational theory shared by neoclassical economics and the non-cooperative game theory are misunderstood in assuming that commitment never takes place in human decisions. 2 • 2 non-symmetric game and 3 • 3 symmetric game as finite, state-dependent quasi-birth-and-death processes were modelled by Tadj and Touzene (2003). A decision support tool for better situational awareness based on the game theory was proposed by Brynielsson (2007). A new model to optimize strategies for three-person discrete dynamic games was developed by Ôzyildirim (1996). The emergence of new economies has put pressure on global supply chains; this problem of transshipment was addressed using the game theory by Reyes (2005). For estimating coalition stability likelihood, in the context of a two-stage cartel game, an algorithm was designed by Olieman and Hendrix (2006).

Security for SMC-based architecture is another area of concern. Otrok et al. (2008) explored the problem of detecting intrusions into wired infrastructure networks using the game theory. Negotiations to reduce greenhouse gas accumulation in the atmosphere were modelled as extensive games of perfect information. Various solution concepts, such as the Nash equilibrium, reaction function equilibrium, correlated equilibrium and bargaining solutions were applied, analyzed and computed by Forgô et al. (2005). Reniers et al. (2009) used a game theoretic model for the prevention of domino effects in the chemical process industry. A thorough analysis of fully mixed Nash equilibria for discrete routing games was performed by Gairing et al. (2008). How imitation games lead to simplifying and unifying perspectives in two different contexts was shown by McLennan and Tourky (2010).

Most of the developments in this area have been interactive; researchers have been providing new insights and even refuting earlier research. Shoham et al. (2007) studied multi-agent learning from the perspective of the evolutionary game theory. As suggested by the title of Shoham et al. (2007) (If Multiagent Learning Is the Answer, What Is the Question?), the ultimate lens through which the multi-agent learning framework should be assessed is 'what is the question', and Mannor and Shamma (2007) addressed this issue by presenting challenges motivated by engineering applications and discussing the potential appeal of multi-agent learning. Existence results for the Allaz-Vila (Allaz and Vila, 1993) forward market equilibrium model, when the M producers have different linear cost functions, was presented by Su (2007).

Nano RFID and Nano WSN will play an important role in future systems. Game-theoretic models of lead-time reduction in a two-level supply chain involving a manufacturer and a retailer are one of their very important applications. The retailer manages the inventory system using the order quantity, reorder point, continuous-review (q, r) policy. To satisfy the retailer's order, the manufacturer sets up his facility, implements a pre-determined production schedule and delivers finished products to the retailer (Leng and Parlar, 2009). A sufficient condition for the existence of a pure-strategy coalition-proof Nash equilibrium in a strategic game was established by Kukushkin, (1997).

In the light of the previous works in this area, we need to develop the Nash equilibrium model for companies introducing nano devices into real markets.

2. Development of a Game Theoretic Model for Nanotechnology

Research into reliability engineering is bound to make an impact on the commercialization of nano devices. During the present study, it was found out that the model developed for reliability engineering may be well suited to be applied in TTC, which is proven by the rate of the commercialization of the nanotech 'TTC model'. The commercialization of nanotechnology depends on many factors including reliability, packaging, availability and cost reduction. Modelling reliability and packaging are the important factors for any nano device to 'hit' the market.

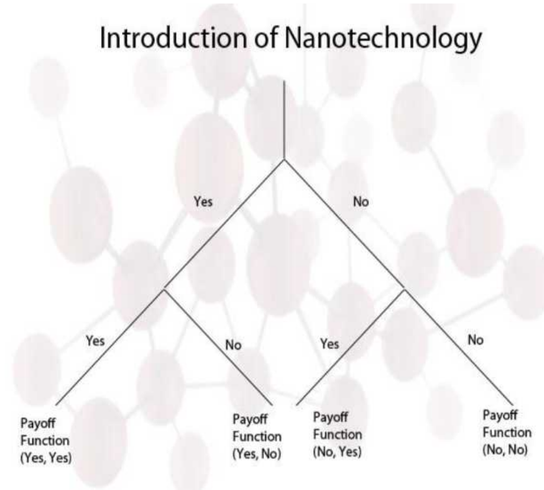

Figure 2. **Game plan showing the possibilities for a company to introduce novel nano material into its current products**

There is a system of options for a company wishing to incorporate nano devices into its production. The strategy set can be a function of many complex moves, a simpler model of which is shown in Figure 2.

If company A decides to introduce a product that involves nanotechnology, it will be followed by company B which will also follow the same strategy. In such a case, we may define the equation as presented further.

A set of strategy profiles, if a company sees another company to develop and introduce strategies, includes:

1. Increase funding in the area;
2. Work on pre-patented technology;
3. Work on reliability and packaging models;
4. SCI research in the specific area need to be monitored;
5. Development of modelling solutions using latest CAD design which includes simulation using HPC;
6. Social implication of the technology developed;
7. Too expensive may be not feasible today.

Our earlier research into Micro Electro Mechanical Systems (MEMS) and other nano devices was focused on seven major areas important in developing the game theory model:

1. Reliability of MEMS (Pathak et al., 2009c);
2. Reliability of CNT (Shivhare et al., 2008);
3. HPC modelling of nanotech (Pathak et al., 2009b; Joshi et al., 2009b);
4. Reliability Nano RFID and WSN (Pathak and Joshi, 2009a; 2009c);
5. Reliability of HDD (Joshi et al., 2009a);
6. Reliability of MEMS fuel cells (Pathak and Joshi, 2009d);
7. Virtual reality & CUDA HPC modelling for reliability computations (Pathak and Joshi, 2009h; 2009i).

These studies can be referred to by companies dealing with nano energy solutions.

Payoff functions:

1. Success
2. Successful product but less reliable
3. Successful but expensive
4. Successful but ethical and social issues
5. Successful but got late
6. Successful but patent complication
7. Successful but government clauses
8. Failure

In the analysis, each strategic move will have a probability dependent on time— $ke^{\lambda_1 t}$

The probability of funding depends on various parameters which need to be explored. The probability for a strategic profile which also depends on other parameters:

$$k'e^{(\lambda_1' + \lambda_2' + \lambda_3' + \lambda_4')t} = ke^{\lambda_1 t} \quad (1)$$

Also, a person has to take a move where the final probabilities of all moves when added give one, as shown in equation 2.

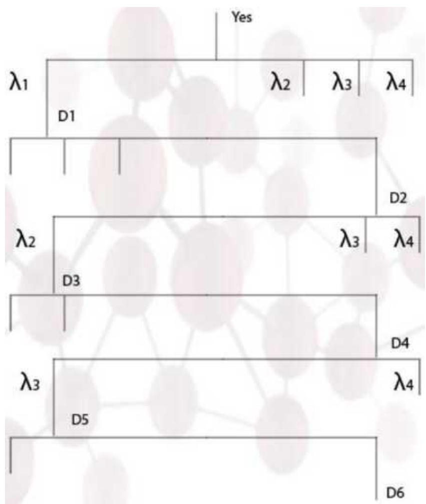

Figure 3. **A game of four strategic profiles and the final payoff**

$$k(e^{\lambda_1 t} + e^{\lambda_2 t} + e^{\lambda_3 t} + e^{\lambda_4 t}) = 1 \quad (2)$$

This equation must hold true as the event is exhaustive at any given point. Now, for solving we have the difference operator Lambda at various points; if we know the probability of 2 out of 3 moves, the 3rd move's probability can be calculated as follows:

$$\lambda_3 = \frac{-\log\left(\frac{-(ke^{-\lambda_1 t} + ke^{\lambda_2 t} - 1)}{k}\right)}{t} \quad (3)$$

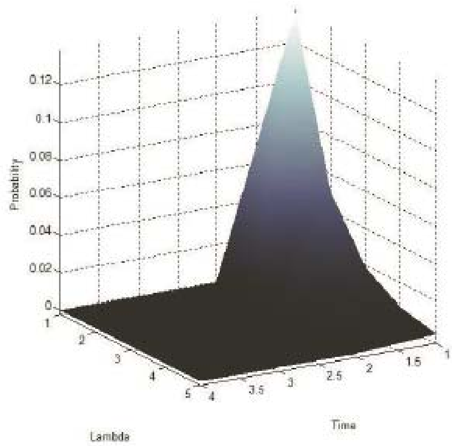

Figure 4. **Probability dependence of one Lambda1 on the overall probability of the system**

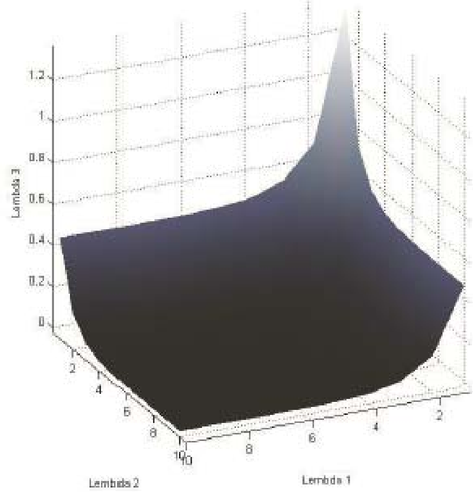

Figure 5. **Lambda for various moves where the variations of Lambda are defined for exhaustive probability moves**

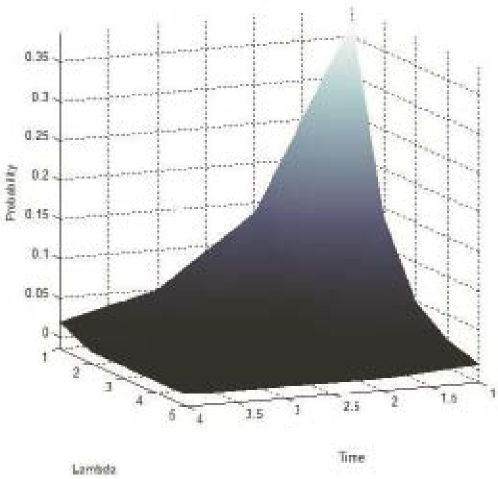

Figure 6. **Continuous function for a defined move**

P of $Lambda_1$ = probability of change funding priorities.

P of $Lambda_2$ = probability of moving to pre-patented technology.

P of $Lambda_3$ = probability of moving ahead on CAD, packaging and reliability.

P of $Lambda_4$ = improving publications patents in the technology.

Each will be an exponential function which varies with the time. The ELambda1, if varies constantly with time, can be assumed to increase or decrease with the value with time, the probability may be assumed as continuous distribution with time.

At this point, we have to take different values of each of them; this will result in the payoff defined as various points.

If we consider a separate case of a specific device, we can see a clear picture of the exact movement of the device towards commercialization.

The implications of innovations in MEMS on WSNs were analyzed by Pathak et al. (2009a) and Pathak and Joshi (2009g); the authors modelled MEMS elements from a device perspective. This work was focused on the development of new models for reliability analysis, which holds the key in our proposed mode. The essence of High Performance Computing (HPC) in the field of nanotechnology and problems encountered by HPC arrangement in applying HPC to nano-enabled calculations were presented by Pathak et al. (2009b). Computational approaches have brought powerful new techniques to calculate reliability supported by experimental and theoretical methods. These approaches play a crucial role in MEMS technology as well shown by Pathak et al. (2009c). The authors also analyzed some of the complex modelling aspects such as multiscale modelling or MATLAB sugar-based modelling as well as the complexities involved in the analysis of nano Radio Frequency Identification (RFID) systems (Pathak and Joshi, 2009a). Moreover, the authors presented the modelling and simulation of nano-RFID systems and introduced some innovative ideas and library development for Nano RFID and its extension for MEMS devices (Pathak and Joshi, 2009b). The reliability modelling that contains methods to calculate reliability function, failure rate function, Mean Time to Failure (MTTF)

and Mean Residual Time (MRT) were proposed for MEMS technology (Pathak and Joshi, 2009c); multiscale modelling of nano solar cells was also discussed (Pathak and Joshi, 2009d). Moreover, it was proved that if HPC is used with multiscale optimization library, the reliability calculation can be accelerated (Pathak and Joshi, 2009c). Finally, Joshi et al. (2009a) showed the impact of the developments in nanotechnology on Hard Disk Drives (HDD), which is a system that can be commercialized in the near future.

3. HPC Framework Used for Simulation

The model developed needs high computation power and is, therefore, implemented on the same HPC setup which was used for nanotechnology-based computations. Implementations of various multifarious aspects of multi-scale modelling on HPC setups were showed by Joshi et al. (2009b). Various aspects of nano simulation were implemented using multi scale modelling on various HPC setups by Pathak and Joshi (2009f); in their paper, the requirements for HPC were met using HPC setup which was used for the computation of reliability and multi-scale modelling.

We did the calculations in C#. Our work was done in Visual Studio. The computation model is shown in Figure 1. Some of the software resources of the development of this project are:

1. C# compiler (Visual Studio 2005);
2. .Net Framework for standard development library
3. (Visual Studio 2005);
4. Microsoft MPI (Message Passing Interface) (Visual
5. Studio 2005);
6. Microsoft XNA Framework (Visual Studio 2005);
7. A good high performance math library for C# (e.g., Extreme Optimization Numerical Library for .NET).

We have chosen C# because it is a multi-paradigm programming language that encompasses imperative, functional, object-oriented (class-based) and generic programming disciplines. Microsoft Visual Studio is the Integrated Development Environment (IDE) for many languages such as C#, C++, Visual Basic, J#, and many other languages which are based on the .NET framework (Pathak et al., 2009a).

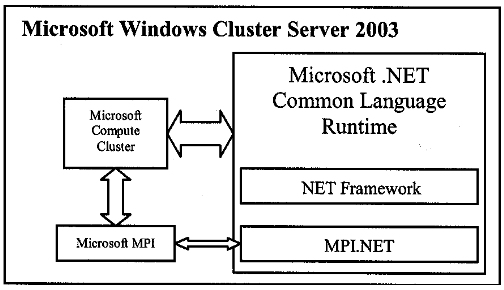

Figure 7. **Our runtime enrivoment**

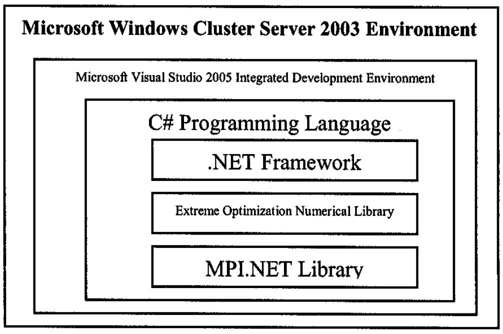

Figure 8. **Our development enviroment**

.NET Framework is a vast library of pre-coded functions and classes to common programming problems. The execution of programs written in this framework is managed by a virtual machine. The framework covers a large range of programming needs in a number of areas such as cryptography, web development, numeric algorithms, networking, User Interface (UI), database connectivity and data access Pathak et al., 2009b). We required a strong set of library functions and classes to support our development, and .NET Framework is an excellent library for that purpose. A standard collection of functions and classes aided us in making our own library promptly by allowing us to construct the key conceptual components of the library only and leaving out the unnecessary parts. If we had started from the base, it would have taken a lot of time, and .NET allowed us to start exactly from where we needed to initiate our work.

Programs written for the .NET Framework execute in Common Language Runtime (CLR), which is a part of the .NET Framework. CLR is a software environment that manages the program's execution and runtime requirements along with many important services such as security, memory management and exception handling. CLR creates a virtual machine for applications to execute, which increases portability by removing the need for the consideration of the capabilities of hardware that executes the code. CLR and class libraries together form the .NET Framework. .NET Framework is included in several versions of Windows such as Windows Vista, Windows XP and Windows 2008. Version

3.0 of the .NET Framework is included in Windows Server 2008 and Windows Vista. For the present study, .NET Framework 3.5 was used.

The computation was done using supercomputing to take in various parameters and predict a more complex system. The system is based on WCCS. Computation on MATLAB for solving the exponential functions as well as computation using extreme optimization library was done.

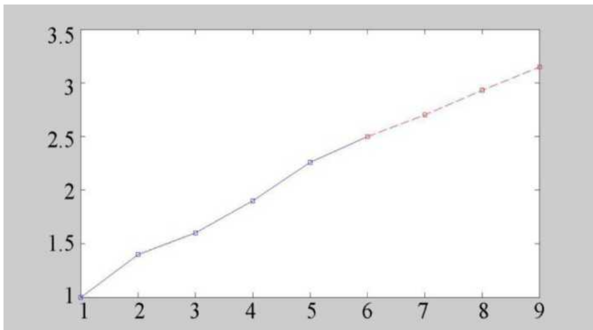

Figure 9. **Speedup vs. configuration for financial system calculations on a 4 node setup**

Conclusions

In the present paper, the game theory was applied for strategic decision-making for companies interested in applying nanotechnology. The Nash equilibrium for a business model for the application of nanotechnology was defined, including the strategies and payoff profiles. The need for high computation power was met by using a legacy HPC model based in Windows Compute Cluster Server and extreme optimization library. The results show that the application of such models can lead to successful implementation of nano devices and cost benefits in the current scenarios. The model takes into account our recent work on reliability engineering and its implication for the commercialization of technology, which also plays an important role in the computation of exponential reliability functions. Various parameters were taken into account with a special focus on reliability and modelling for the commercialization of nanotechnology.

Short Summary. A classical game is defined depending on various parameters required to predict rate of commercialization of Nano Device. The rate of commercialization is developed and then the gaming model is then modeled using the commercialization theory. Equilibrium cases are studied pertaining to business in nano domains and a proposal on impact of various strategic profiles with the payoff is computed. This study is applicable in the study of nanotech wars which may use extensive use of nano materials. It can also be used for developing the time taken for commercialization of the nano device. The strategy of a company to commercialize and implement the novel nano device can be affected by the other company trying to enforce the same where the need of strategic decision making emerges. The model assists the company in decision making during such strategic conditions. In this case the modeling complexity increases which has been addressed as well as simplified for better understanding of the phenomenon. Results show that implementation of such models can lead to successful implementation and cost benefits for implementation of nano devices in the current scenarios.

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STRATEGINIŲ SPRENDIMŲ PRIĖMIMAS IR LOŠIMŲ TEORIJOS PRITAIKYMAS NANOTECHNOLOGIJŲ KOMERCINIAMS TIKSLAMS

Rohit PATHAK, Satyadhar JOSHI, Arpit LUDHIYANI

Santrauka. Lošimų teorija sėkmingai gali būti taikoma tik ištyrus praktinius jos taikymo modelius. Straipsnyje apžvelgiamos modelių kūrimo problemos remiantis nanotechnologijų komerciniu pavyzdžiu. Vertinami situacijų skaitmeniniai nanoįrangos modeliai, pusiausvyros situacijos, jų pritaikymas skirtingiems strateginiams atvejams plačiau komerciniais tikslais taikant nanoįrangą.

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