ISSN 1822-8011 (print)
ISSN 1822-8038 (online)
INTELEKTINĖ EKONOMIKA
INTELLECTUAL ECONOMICS
2011, No. 1(9), p. 117–134

BUSINESS IMPLICATIONS OF RECENT DEVELOPMENTS IN NANOTECHNOLOGY FOR MICRO SCALE DEVICES

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Abstract. The paper describes the commercial aspects of developments in Nanotechnology. We have elucidated the implications of reliability modeling, multi scale modeling and HPC modeling (High performance computing) for product commercialization of Nano devices. Various modeling options are discussed that can aid the modeling of commercially viable nano products. A model is proposed taking in account the most major aspects of nanotech commercialization and is linked with other technical aspects as well social factors. This work gives deeper insight on understanding the issues involved and business prospectus of nanotechnology. The motivation is taken from our earlier work on reliability engineering and the result shows that the theory of exponential models for Survival Rate function after proper ramification can be applied on the TTC (Time to commercialize model) modeling.

JEL clasification: C600, C680, C790, C890.
Keywords: Nanotechnology, Reliability, Modeling, Business, Time to commercialize.
Reikšminiai žodžiai: nanotechnologijos, patikimumas, modeliavimas, verslas, komercinis laikas.

I. Introduction

Nanotechnology with its advent have placed before us a number of opportunities which were never imagined before. Nanotechnology can simply be assumed to take the technology to next level such that after micro its down to nano. Nanotechnology itself is very diverse field such that it can be implemented by taking the present products to nano scale or making a new product itself with eye on nano scale. Nanotechnology is becoming the most talked about field in the 21st century. It has become important such that the number of publications or patent filing have increased exponentially which was unimagined. Nanotechnology patent filing has become a major hurdle such that there is both a lack of knowledge among patent officer as well as the greed of earning profits by the product holder, in this field, such that they file the patents for their products by just changing a product to nano scale which cannot be assumed to be a novel product because of just changes in its scale rather than in its properties. Nanotechnology have implications on every known fields such as medicine, electronics and energy and it has the potential to impact human lives forever.

Consumers today have the option to buy various nanotechnology products which have been researched and produced over decades. Today nanotechnology product can be considered as costly but with its development and better research facility it is bound to become much cheap and within reach of everyone. Several companies are today commercializing their nano products slowly but steadily. It can be easily assumed that several other companies will not want to miss the opportunity and will sooner or later join the already established names in the business. Governments are not behind much and are sensing the opportunity with respect to its long term effect of the nation as a whole and its claim for power projections in the world by using nanotechnology as the medium. Governments of US, China, Japan are taking nanotechnology seriously and terming it as the next technology revolution. The country which will not be investing in nanotechnology now will be left behind in the race for domination in 21st century.

With all this advancement in nanotechnology it is also important to analyze the impact of this new field on the human being itself. Today the public opinion is in favor of nanotechnology which cannot be said for tomorrow since as and when this technology develops more and more people will come to knowledge of it and the opinion can change with visibility of its good or bad effects.

Considering all the scenarios and various development in nanotechnology Business implications are studied and the model of commercialization are studied and implemented

II. Current Scenarios and Analysis of State Of Art Technology

Nanotechnology is fast gaining the much needed momentum; this can be confirmed by the recent increase in nanotechnology patents which in between 2000-04 have been at 16.5% as compared to a growth rate of 0.7% in the same period for other patents [1].

Also the nanotechnology research literature represented by the Science Citation Index/ Social Science Citation Index(SCI/SSCI) (SCI 2006), which shows that nanotechnology publications have grown from 11,265 records in 1991 to 64,737 records in 2005 also affirms this growth, as shown by Kostoff et al [2].

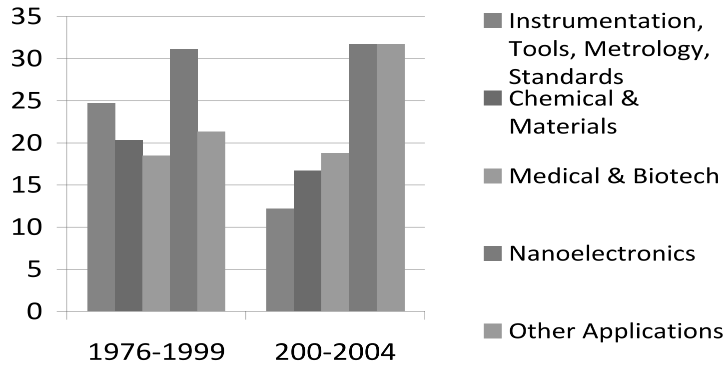

Figure 1. Trend in nanotechnology application areas [1]

The prior knowledge of IP regimes in any field is of vital importance in any scientific work associated with enormous risk. It is desired that this condition is well understood and applied. Since nanotechnology is a very research oriented field and any product will take lots of research expenditure before bearing fruit it is very important for nanotech players to get patents file as early as possible. This has resulted into a nanotechnology enabled gold rush in which the researchers need burgeoning profits from their product as shown in [28].

With the innovations of new technologies intellectual property rights often becomes a hurdle; when it is granted to a certain individual or an organization they claim a share of the profit of new products derived from their existing patented product. IP regime often over values the product of the patent holder and gives him share of profit from the products which he does not deserve at all. This effect is studied on the subject of nanotechnology is studied by Wartburg et al [8].

The effect of nanotechnology has been such that designing materials at a scale of nanometer is fast gaining pace and thus with it the desire to get legal protection i.e. patent for the newly designed product [20]. But the patenting of the product is a major hurdle in nanotechnology since it is a multidisciplinary field in which the classification of an invention is very challenging. Though reducing any known invention to the size of nanometer is considered obvious, the inventor can still file a patent if he can prove that the properties of the invention are unique to the nanoscale. The biggest challenge faced by the patent officers with this field is that it requires a lot of understanding on part of them so that they are at least able to distinguish between a nanotechnology product from a non-nanotechnology one [17].

This patent information is important because in our proposal we have linked the growth of increase of patents into our model to predict commercialization of a specific Nano device. This data was used to build a basic model which was then implemented to match with the commercialized devices.

The most important part of commercialization will be to evaluate the technology; this is not the work of an individual but a team of enthusiasts and risk takers having a perfect goal in their mind. The model explored in this paper can also be applied in this area.

The rush for this emerging new field can be seen from the measures from the various governments of the world are taking and no one wants to be left behind. The importance of nanotechnology is such that Countries holding the leadership positions in nanotechnology implementation such as United States, Japan, European Union and China will have a huge advantage in the economic and military sphere for many decades to come [4].

Nanotechnology is being viewed as a very important factor for the coming years in Japan [31] such that in the 2nd Science and Technology Basic Plan (2001–2005), the area of nanotechnology and materials is designated one of the four prioritized areas in funding. Also the advances in the field of health care with the help of nanotechnology have been taken note [10] in case of London and UK as a whole. London is getting competitive facilities so that it stands a chance in global sphere in this field. In [9] global perspective of sectored nanotechnology innovations is studied with an aim to monitor the worldwide developments in nanotechnology research.

Process based products such as nanotechnology differs in the relationship between product and process innovation w.r.t. assembled products. Since the change in process innovation will likely result in change in product shown by Linton and Walsh [15]. The sequence of product to process innovation is different for process based products such as nanotechnology and similar for other assembled products. Nanotechnology is not a single unit or entity but a cluster of several fields of technology shown by Martin et al [5]. The other proposition states that there is no widespread interaction between the various technologies but a punctured interaction.

Inventions of new products with the help of nanotechnology is proving to be very beneficial since it helps reduce costs and also prevent our environment from getting deteriorated .To get benefits from this technology it is important that we make certain attempts in positive direction such as bringing investments in study of properties at nanoscale, making manufacturing of nanomaterials low cost and also studying the effects of nanotechnology as shown in [6].

Advancement in nanotechnology will lead to job opportunities in this field and will require highly skilled labor studied in [12]. A prediction by National Science Foundation stated that by 2015 there will be creation of 2 million jobs in the field of nanotechnology. There is a market in this field but it is very limited and is only confined to the laboratories of universities and governments. The limited resource available in this field for training is being fulfilled through a principal investigator approach i.e. in it a student is attached to one faculty member's lab, rather than to a formal program [12].

How nanotechnology will change the process of innovation is shown in [18]. As the field of nanotechnology takes shape the varying applications of it are coming to the forefront, one such application is in the field of medicine called "nanomedicine" which is gaining momentum, but various agencies are looking at it from science and research perspective and not as a commercial product given by [19]. Nanotechnology promises to create a library of sophisticated drug delivery systems that integrate molecular recognition, diagnostic and feedback [35].

There are both benefits and risks of nanotechnology. A balance is studied between the two by Roco and Bainbridge [7]. It has the potential to make a lot of improvements in various aspects of society like improving productivity, making considerable changes in future economic scenarios & thus improving the quality of life.

Nanotechnology research and development will help in many fields [33]. When the funds for R&D are given every factor is worked upon such that the social and commercial aspects of nanotechnology are not being ignored and more and more importance is being given on how the nanotechnology development will help the public at large.

With the advancement in nanotechnology there are arising a great amount of other problems that it poses to Earth and Mankind which were not considered till now. These problems can be called as EHS risks i.e. Environmental, Health & Safety risks, arising from this relatively new technology [3]. One thing which gives a soothing effect for nanotechnology is that the public opinion is in its favor but as this technology will advance and people will be able to view its effects, their opinion will change.

There may not be specific nanotechnology related ethics but there is an ethics of new & emerging science and technology (NEST) discussed in [36]. Many issues concerned only to nanotechnology has been discussed which raise various ethical utilization of nanotechnology.

This risk factor is also considered in developing the model which plays a part in device commercialization, where its effect needs to be carefully substituted as a parameter is the developed equation.

According to [11] Sustainable governance in emerging new technologies such as nanotechnology is of vital importance. The analysis helps to conclude that there is an urgent need for both public interest and public institutions in field of nanotechnology development.

Nanotechnology is fast becoming new growth innovator. Theoretical approaches are given in [26] such that the entrepreneurs are able to access the various scenarios associated with the setting up of new businesses in nanotechnology.

In [27] recent trends are studied in which private enterprises are themselves making regulatory mechanisms in launching and managing of nanomaterials such that governments are seeing the developments by sitting on the fence.

The research in [21] comprises of seven different papers reviewed by the authors. The seven papers are focused on many different aspects of *National and Regional Nanotechnology Policy*.

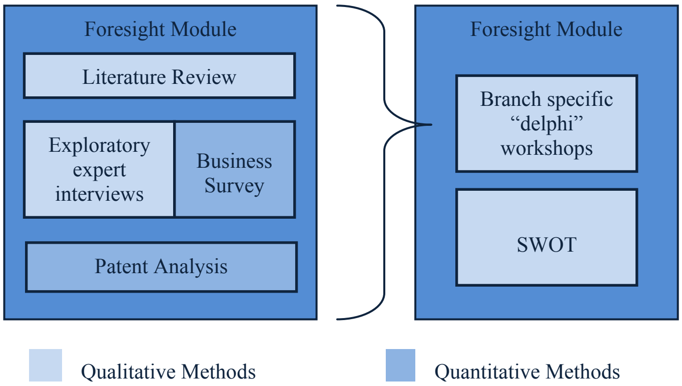

Figure 2. Integrating market research and foresight modules to assess the economic potential of nanotechnology[13]

Scientific issues concerning nanotechnology are given by [14]:

- Our understanding of nanoscale energy and mass transport at different levels i.e metal-metal, solid- fluid etc. is limited and believed that it is rich in scientific content but is not fully realized.
- Electron energies are quantized in a nanoscale structure, leading to novel effects.
- Need for multi-physics and various computational models such that they can address the molecular and electronic structure, physical and chemical dynamics of nanoscale structures.

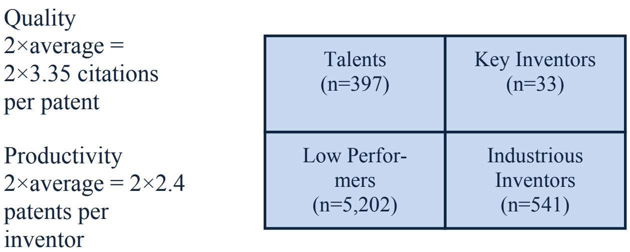

Figure 3. Nanotechnology key inventor identification matrix.[16]

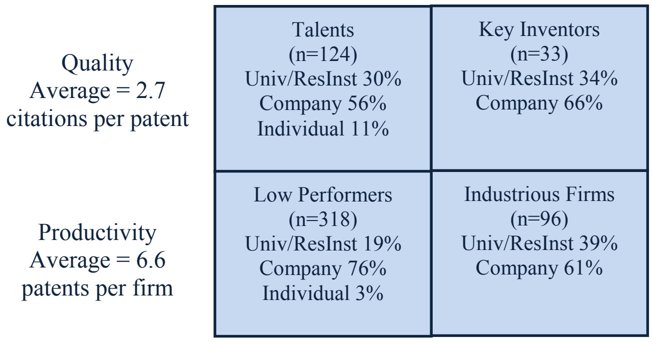

Figure 4. Distribution of nanotechnology key firms.[16]

Table I. Properties and effects that play an important role at nanoscale [22]

Properties and effects perceived at nano scale	Example of Application (possible)
Higher surface to volume ratio – which causes enhanced reactivity	Catalysis, solar cells and batteries
Lower percolation threshold	Conductivity of materials
Increased hardness with decreasing grain size	Hard coating and think protecting layers
Narrower band gap with decreasing gram size	Opto-electronics
Higher resistivity with decreasing grain size	Electronics
Increase wear resistance	Hard coating an d tools
Lower melting and sintering temperature	Processing of materials and low sintering materials
Improved transport kinetics	Batteries and hydrogen storage

Table II. Scenario that exist [25]

Scenario method step	Output	Participants other than facilitation team
Step 1: project setup	Key business focus, key business problem and organizational knowledge gap.	Entrepreneurial team / management team of small nanotechnology firm.
Step 2: interviews and analysis	Interview overview with issues related to business focus and business problems.	Interviewees – full range of firm's decision makers related to the context of key business problems.
Step 3: scenario agenda workshop	Overview of critical uncertainties related triggering wild-card options and scenario agenda.	Scenario team as an extract of the entrepreneurial team / management team.
Step 4: scenario workshop	Scenario story-lines based on impact/unpredictability matrix, including wild-card analysis, representation of cause/effect and implications for organization.	Full group of entrepreneurial team management team of small nanotechnology firm.

A more detailed survey of Nanotechnology & its Application can be found in [23, 52].

Table III. Action and investment trends [24]

Type of Nanotech actor	Number of global actor
Large companies	117
Subsidiary or joint ventures	83
Startup or small companies	462
Research institutes or universities	388
Total	1050

Data from the national phone survey of Americans' perceptions about nanotechnology is presented in [29]. The data presents that the opinion of the public is in its initial stages. Americans' initial reaction to nanotechnology has been positive as they view nanotechnology can be potentially used for eradication of human diseases but they also see as a risk to their privacy as new surveillance devices are being made.

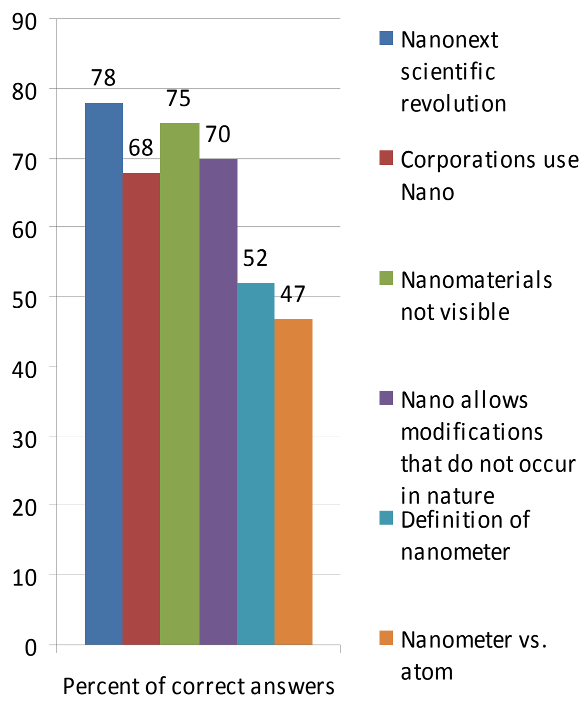

Figure 5. Knowledge levels about nanotech-related issues

Issue of connect with the public on nanotechnology is discussed in [34]. Though the public have a positive view on nanotechnology, this picture can change if scientific community and other related organizations do not make an effort to bring public in the nanotechnology landscape.

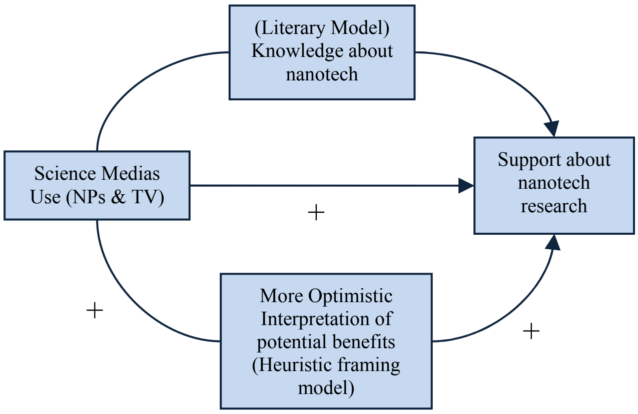

Figure 6. Science Literacy and Heuristic models of attitude information [30]

The attitude of people towards new emerging technologies such as nanotechnology is studied in [30]. The findings in research suggest that people form opinions and attitudes even in the absence of necessary scientific information.

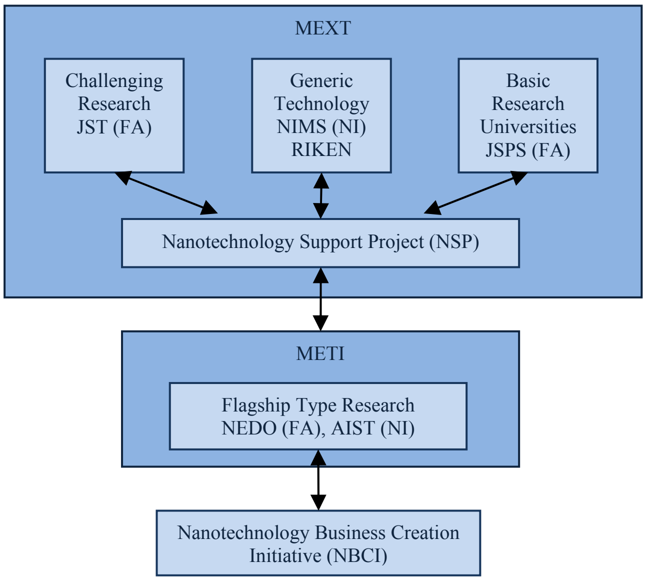

Figure 7. Nanotechnology Research, Development and Business organizations in Japan. FA: Funding Agency, NI: National Research Indtitute. Research, development and Business for Japan [31]

Nanotechnology is gaining both private and public funds with its emergence as a new technological breakthrough. This is accomplished to bring new and more advanced products based on nanotechnology. Issues related to the commercialization of nanotechnology are discussed in [32] from a fund prospective.

III. Implementation of Proposed Model

The major implementation challenges are reliability, packaging and comprehensive modeling of each and every nano system as well as nano scale phenomenon. Modeling to detect failure is an area that needs to be extensively worked with data from the research lab and commercialized prototype. Rate of commercialization for CNT base devices is based on cost reduction and environmental factors. Green Energy benefitting from Nanotechnology is quite eminent where new ideas are proposed in recent years using nanotechnology. Nano RFID holds the key for identity management and banking using Nanotechnology.

A. Assumptions for the model

Our earlier research MEMS and other nano devices can be distributed for seven major areas which forms the basis of this proposal:

a) Reliability of MEMS [24]
b) Reliability of CNT [36]
c) HPC modeling of nanotech [23, 31]
d) Reliability Nano RFID and WSN [25, 27]
e) Reliability of HDD [30]
f) Reliability of MEMS fuel cells [28]
g) Virtual Reality & CUDA HPC modeling for reliability computations [35, 37]

Research in reliability engineering will have its impact on commercialization can be clearly seen in the earlier work. During the study it was found that the model developed for reliability engineering will well be suited to be applied in TTC. “TTC model” for Commercializing on Nanotechnology depends on many factors including reliability, packaging, availability and cost reduction

Parameters of the following needs to be calculated using appropriate operators which are defined as follows:

- TTM = f (Reliability, Multi scale optimization, Social issues, investment)
- Operator R (models, accelerated testing, redundancy, Packaging)
- Operator M (multi scale and multi physics optimization for accurate predictions)
- Operator S (Social and ethical issues)
- Operator I (funding and investment)
- TTM= $K_{raw\ time}$-Operator (R+M+S+I)

Reverse reliability commercialization factor, is a function in which we can assume the function of time to failure as identical to time to market function is proposed and implemented in this work. Using this we can form a mathematical basis for predicting the commercialization of the system. This model is derived from reliability engineering which was developed earlier.

TTF is found to be an exponential function and therefore we can link it with factors like time to vanish or commercially not viable probability distribution.

In reliability engineering we have *f(t)* depended on frequency MEMS device operate, viscosity of the medium in which MEMS device operates, force exerted on the device, electrostatic forces and electromagnetic forces it is subjected to, material which defines the strength of the device in various forms. Now redefining the same for TTC function we need to modify the parameters as follows:

υ= frequency of operations

κ = stress it is subjected to, which related to the environmental and ethical issues

η = inertia in research in the subject

ϵ_C = effect like seeding

ϵ_M= market forces

$M_{(\rho, C, r)}$ = material of the device, cost issues

$\bar{I}$=current flowing in the means number of papers published in SCI

T_o=in some cases temperature may also be a cause, which is news in media.

f(t) is a function of $\upsilon, \kappa, \eta, \epsilon_C, \epsilon_M, M_{(\rho, C, r)}, \bar{I}, T_o$

We have discussed the physics of commercialization of these devices, it is assumed that the function will be exponential with some modification since it's a standard reliability function used which can be modified for the TTC issue.

It is obvious that f(t) will increase with $\upsilon, \kappa, \eta, \epsilon_C, \epsilon_M, M_{(\rho, C, r)}, \bar{I}, T_o$

As these parameters are linked to the TTC therefore to insert their equivalent they are calculated by operator f' where increase in any of them will increase the TTC device, this operator converts the respective value to a function that needs to be inserted in the main failure probability distribution equation.

Also it is obvious that the variation will have an exponential distribution for the failure rate distribution which can be derived from the basic principle of exponential distribution of reliability theory.

So,

$$f(t) = (f(\upsilon) + f(\kappa) + f(\eta) + f(\epsilon_C) + f(\epsilon_M) + f(M_{(\rho, C, r)}) + f(\bar{I}) + f(T_o)) \times e^{-(\upsilon + \kappa + \eta + \epsilon C + \epsilon M + M(\rho, C, r) + \bar{I} + To))t} \quad (1)$$

$$\lambda = (f'(\upsilon) + f'(\kappa) + f'(\eta) + f'(\epsilon_C) + f'(\epsilon_M) + f'(M_{(\rho, C, r)}) \quad (2)$$

It is assumed we are given all parameters and they remain constant throughout the cycle of the Nano device then (f(υ) + f(κ) + f(η) + f(ϵ_C) + f(ϵ_M) + f($M_{(\rho, C, r)}$) + f($\bar{I}$) + f(T_o)) = λ is assumed constant for computation that is being done on MATLAB.

This formulation developed needs to be modified as the exact dependencies of a case specific Nano device such as the proposed models in [24]. For example ƛ need to derive for Nano RFID which has MEMS based antenna and transponders.

At any given point there is a probability of the device to either get success or get fail as per the commercial prospective.

This is a generic success in commercialization distribution for system is under process to get commercialize, Thus the system can be taken to have probability

$$f(t) = \begin{cases} \lambda e^{-\lambda t} & for\, t > 0, \lambda > 0 \\ 0 & otherwise \end{cases} \qquad (3)$$

This function is approximated by a continuous variable where we assume the Time to success T is continuously distributed with probability density f (t)

For a Proposed device it depends in the frequency of funding, publications, total number of times it gets media coverage. For the Survival Rate function, the system can be discontinuous because it must have its value 1 at t=0.

System A is defined as

$$f(t) = \begin{cases} (f\lambda)e^{-(\lambda f)t} & for\, t > 0, \lambda > 0 \\ 0 & otherwise \end{cases} \qquad (29)$$

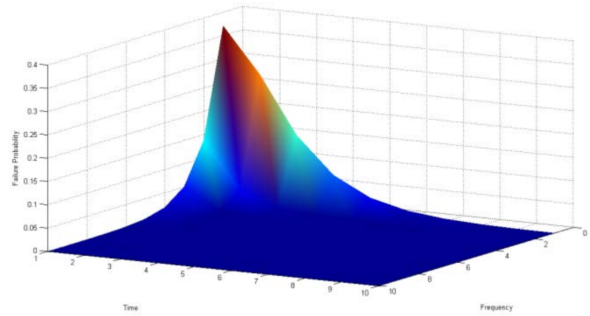

Figure 9. Probability distribution for system A.

System A

$$f(t) = \begin{cases} (\lambda + f)e^{-(\lambda + f)t} & for\, t > 0, \lambda > 0 \\ 0 & otherwise \end{cases} \qquad (30)$$

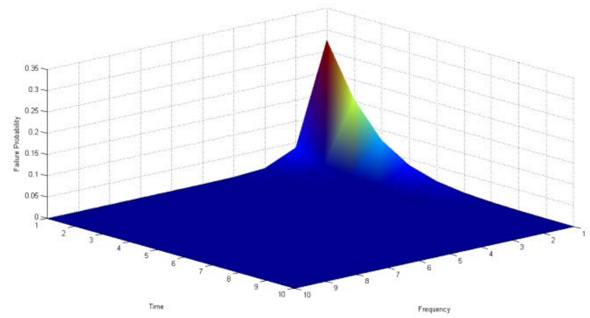

Figure 10. Probability distribution for system B.

System C

$$f(t) = \begin{cases} (f\lambda + f)e^{-(\lambda f + f)t} & for\, t > 0, \lambda > 0 \\ 0 & otherwise \end{cases} \tag{31}$$

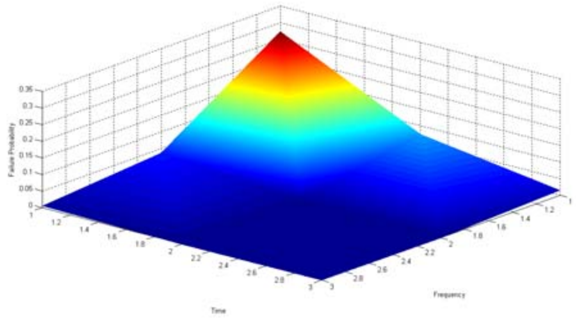

Figure 11. Probability distribution for system C.

The three models discussed can be applied in different cases which are applicable to CNT based devices; MEMS based devices and hybrid cases. The assumptions of models are that CNT based devices have slow commerciality and therefore their operator in exponential function should reflect this factor, whereas MEMS and NEMS are comparatively easier to commercialize. The third case can be assumed for a hybrid case which has both CNT and MEMS devices with interchangeable operations in the device.

1. System A for CNT based System (since the frequency effect is more catastrophic for the device)
2. System B for MEMS based System
3. System C for CNT and MEMS system or hybrid case

Another way to implement this model is that the operator is assumed to operate between three time intervals t_1, t_2 and t_3.

1. System A for early failure
2. System B for constant failure (where the change of probability is equal)
3. System C for wear out failure

Case study of CNT based devices (Reliability, Packaging, Multi scale optimization, Social issues) are needed for building its model .This is a Reverse function of failure rate which takes the form of chances of device to get commercialized.

The implications of innovations in MEMS on Wireless Sensor Networks (WSN) are analyzed in [47] and have modeled MEMS elements from a device prospective. 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 have been presented in [48]. Computational approaches have brought powerful new techniques to calculate reliability supported by experimental and theoretical methods. These approaches play a crucial role in Micro Electro Mechanical Systems (MEMS) technology as shown by Rohit et al [37]. The Reliability modeling codes to calculate reliability function, failure rate function, Mean time to failure

(MTTF) and Mean Residual time (MRT) are proposed for MEMS technology. Some of the complex modeling aspects such as Multi Scale modeling, MATLAB Sugar based modeling are given in [41] also the complexities involved in the analysis of Nano RFID (Radio Frequency Identification) systems are shown. The modeling and simulation of Nano-RFID systems have been shown in [49] and demonstration of some novel ideas and library development for Nano RFID and its extension for MEMS devices is also shown. The Reliability modeling contains methods to calculate reliability function, failure rate function, Mean time to failure (MTTF) and Mean Residual time (MRT) are proposed for MEMS technology by [42]. Multi Scale modeling of Nano solar cells is proposed in [44]. In [50] it is proposed that High Performance Computing (HPC) if used with multi scale optimization library then the reliability calculation can be accelerated and also research in reliability of MEMS. Impacts of developments in nanotechnology on Hard Disk Drives (HDD) have been shown in [43]. Implementations of various multiferous aspects of multi scale modeling on HPC (High Performance Computing) setups have been shown in [40]. Multifarious aspects of nano simulation are implemented using multi scale modeling on various HPC (High Performance Computing) setups by Rohit et al [51]. Startup on Nanotechnology gave us experience that helped us to calculate the balance out our research and the various parameters involved [52].

IV. Conclusion and Validation of Model

The impact of innovation and the rate of commercialization have been shown and also defined mathematically with a computational model. Relation of business commercialization with parallel research in other domains is also shown with an extensive focus on reliability engineering. Development of model of commercialization of Nano devices is explored and the theory developed now needs to be tested with an industry partner. Earlier research done by us is cited and the problem of commercialization is then solved using reliability models. This research is derived from research in modeling, reliability which can be implemented on the earlier engine for reliability engineering. We are working on implementing this model on MATLAB which is then scalable to run on HPC setups in case of more commutations power like Windows compute cluster server and other HPC installations.

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MIKROĮRENGINIŲ NANOTECHNOLOGIJŲ VERSLO REIKŠMĖS PLĖTRA PASTARUOJU METU

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Santrauka. Svarstant nanotechnologijų komercinius aspektus, nušviečiamos nanoįrenginių patikimumo ir daugiaskalio bei kompiuterinio modeliavimo prielaidos. Pateikiamas modelis, kuriame atsižvelgiama į šių aspektų techninius bei socialinius veiksnius. Darbe, remiantis anksčiau pateikta patikimumo inžinerijos motyvacija, tikslinama nanotechnologijų prielaidų ir verslo perspektyvų samprata. Parodyta, kad išgyvenimo normos funkcijos eksponentiniai modeliai gali būti taikomi modeliuojant laiką, būtiną komercinio įsisavinimo modeliavimui.

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