THESIS ON MECHANICAL AND INSTRUMENTAL ENGINEERING E57

Fractal Approach for Multiple Project Management in Manufacturing Enterprises

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any degree or examination.

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MASINA- JA APARAADIEHITUS E57

Fraktaalne lähenemine multiprojekti juhtimisel tootmisettevõtetes

SERGEI KRAMARENKO

TTÜ KIRJASTUS

ABSTRACT

This thesis is focused on the planning problems of production processes in manufacturing for small and medium enterprises (SMEs), where all business activities are performed on the basis of multiple projects practice integrated in. These problems have received great attention from researchers and practitioners over the last decade. The reason is an exceptional importance of non-single project implementation to reach total profitability, while complexity of the project environment keeps increasing.

The aim of this research is to find new approach for rapid planning and assessment of parameters for the case of multi-project management (MPM). The author proposes an approach that suggests new methods for maximizing utilization of existing resources within a single manufacturing enterprise. The basis for achieving this goal is based on the assumption that multi-project is a complex system, which is directed by the complexity theory. Fractals represent a way of dealing with complexity; they organize the complex system through the iteration and integration of the simple units and common control rules. Using the fractal approach in MPM does not require that the practitioner has special knowledge in managing complex system and complexity theory.

This research covers the overview of various complexity types and measures. Some features from the complexity theory are discussed with regard to changing research paradigm (from Newtonian/reductionism to chaos/complexity). The fractal idea is applied and reformed into a framework of production planning in MPM environment. The author also explains what provides an effect of self-organization in project team-work. Performance of projects and post-mortem analysis are realized through the application of artificial neural network (ANN), particularly self-organizing map (SOM) software.

The author contributes to MPM study in general and manufacturing planning procedures for SMEs in particular. A deliberate deviation from ordinary optimization techniques in operations planning makes sense. Successful application of some concepts from the chaos/complexity theory (fractal, entropy, self-organization, and nonlinearity) attests the novelty of the research.

The results of the research demonstrate practical significance of the approach, viability of its mathematical model, and adequacy of theoretical grounds which it is based on. Concluding remarks shed a light on apparent advantages and weaknesses of the proposed approach, meanwhile reflecting the perspectives of future research.

Keywords: multi-project management, manufacturing, complexity theory, fractal.

KOKKUVÕTE

Käesolev väitekiri on keskendunud planeerimisega kaasnevatele probleemidele tootmisprotsessides väikese ja keskmise suurusega tootmisettevõtetes, kus kogu majandustegevus tugineb multiprojekti (MP) põhimõttele ning on integreeritud ettevõte praktikasse. Need probleemid on pälvinud teadlaste ja praktikute suurt tähelepanu viimase kümnendi jooksul. Põhjuseks on oluline MP juhtimine ja rakendamine ettevõtete kogutulususe saamiseks, samas kui projekti keskkonna keerukus on pidevalt kasvamas.

Selle uurimistöö eesmärk on leida uus lähenemisviis kiire kavandamise ja hindamise näitajate MP juhtimise jaoks. Autor teeb ettepaneku uuele lähenemisviisile ja kasutada uusi meetodeid olemasolevate ressursside maksimaalseks rakendamiseks ühes tootmisettevõttes. Selle eesmärgi saavutamise aluseks on eeldus, et MP on komplekssüsteem, mis on reguleeritud komplekssuse teooriaga. Fraktaalid esindavad viisi, mis tegeleb komplekssusega. Nad korraldavad kompleksüsteeme iteratsiooni kaudu ning integreerides lihtsate üksuste ja tavaliste fraktaalide juhtumiste eeskirjade abil. Kasutades fraktaali lähenemisviisi MP korral, ei eeldata spetsiaalseid teadmisi kompleksüsteemide juhtimisest ja teadmisi komplekssuse teooriast. See uuring hõlmab ülevaadet erinevatest keerukuse tüüpidest ja nende mõõtmistest.

Mõningaid karakteristikuid komplekssuse teooriast on arutatud arvestades uurimistöö paradigma muutumist Newtoni/vähendamise teooriast kaose/komplekssuse teooriaks. Fraktaali ideed on rakendatud tootmise planeerimise MP juhtimise keskkonnas. Autor selgitab ka, mis tekitab ise-organiseerumise efekti projekti meeskonna töös. Projektide efektiivsus ja lõppanalüüs on realiseeritud tehisnärvivõrgu tarkvara kasutamisega Kohoneni algoritmi baasil (SOM).

Autor panustab MP uurimisele üldiselt ning tootmise planeerimise protseduuridele väikese ja keskmise suurusega tootmisettevõtetes. Tahtlik kõrvalekalle tavalistest optimeerimismeetoditest, mida kasutatakse tootmisplaneerimises, on mõistlik ja põhjendatud. Osade kaose/komplekssuste teooriast pärit rakenduste edukas kasutamine (fraktaal, entroopia, ise-organiseeritus ja mittelineaarsus) kinnitab uurimistöö uudsust.

Uuringute tulemused näitavad lähenemise praktilist tähtsust, selle matemaatilise mudeli elujõulisust ja teoreetiliste aluste adekvaatsust, millel ta põhineb. Lõppmärkused heidavad valgust selgetele eelistele ja puudustele väljapakutud lähenemiseviisis, samal ajal peegeldades väljavaateid tulevastele uuringutele.

Märksõnad: multiprojekti juhtimine, komplekssuse teooria, fraktaal, tootmine.

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ABBREVIATIONS

ANN	- Artificial Neural Network
BFU	- Basic Fractal Unit
CAS	- Complex Adaptive System
CNC	- Computer Numerical Controlled
CPM	- Critical Path Method
ERP	- Enterprise Resource Planning
FP	- Fractal Project
MPE	- Multi-Project Environment
MPM	- Multi-Project Management
MTO	- Make-to-Order
NP	- Non-deterministic Polynomial-time
NPD	- New Product Development
NPV	- Net Present Value
PERT	- Program Evaluation and Review Technique
PMBoK	- Project Management Body of Knowledge
PMI	- Project Management Institute
RCMPSP	- Resource-Constrained Multi-Project Scheduling Problem
SME	- Small and Medium Enterprises
SOM	- Self-Organizing Map

CONTENTS

1. INTRODUCTION

1.1. Background

Business and organization environments are characterized with distributed, decentralized, and highly dynamic business processes where unpredictable situations occur frequently. To survive, companies must increase product portfolio, reduce time-to-market, shorten product life cycles and at the same time maintain good product quality and reduce investment costs. Competitive threats are much worse for small and medium enterprises (SMEs) which are reengineering their production and management systems to compete successfully. No individual company on its own is able to be competitive and provide the spectrum of products and services around products to satisfy today's customer demands. To face these challenges organizations have to become more flexible, adaptable, to easily find and integrate with partners for working in networks. SMEs have to cope with the increasing rate of change and complexity of a highly competitive environment, a more comprehensive pool of skills and resources, economy of scale and product portfolio diversification. Engineers started using projects in order to increase the effectiveness in resources (i.e., time, labour) management and business targets achievement. Projects are complex endeavors and project outcomes are far from being certain. Project management owes its existence as a management discipline to the complex, high technology undertakings like space program and nuclear power development. Even though the modern project management discipline has been around for almost sixty years, delivering successful technology projects is still an obstacle for many organizations.

Projects and project management serve as primary capabilities of an organization to respond to changes and thereby maintain a competitive edge. A lot of organizations in different industries perform in the project-based environment. Projects may be considered as building blocks in the design and execution of future strategies of the organization [39]. While the management of individual projects is difficult, the situation becomes much more complicated when there are multiple projects ongoing within an organization.

Practically every manufacturing enterprise manages a number of projects comprising the portfolios (strategically tied projects) or multiple projects (parallel and/or concurrent projects). One of the major problems are dealing with the complexity resulting from the multifunctional aspect of projects, which needs a clear definition of the objectives and the roles that each manager of an enterprise has to perform, and to develop a framework for making decisions regarding the strategic goals [123]. The modern industrial situation imposes some complexities on managing multiple projects, in particular such as high uncertainty and dynamics, huge array of relationships and interdependencies, and so forth. Encountering these project properties a manager has to balance a lot of details to make the right (sufficient and/or optimal) decision in the context of particular constraints. Therefore the notion of complexity in multiple projects has to be discussed thoroughly, at the same time, elaborating and validating the decision framework for dealing with it.

In managing projects, it is required to maintain control over a diverse range of projects, balance often conflicting requirements with limited resources and coordinate the projects to ensure the targeted organizational outcomes are being achieved. With a high number of projects all above mentioned requirements have to be tracked enormously strictly. It implies that a multi-project management (MPM) becomes considerably complex system demanding much time and skills not only from a project manager but every participant in this context. Some of the main causes of project failures in multi-project environment (MPE) are [14]:

1. Hard to coordinate project technological planning.
2. About 80% of results stay out of usage.
3. Weak collaboration between business and operation managers and etc.

There are a number of software products for MPM like Microsoft Portfolio and IBM FocalPoint which help project managers to efficiently handle expenses of projects, timesheets, to provide fast and accurate billing with great visual representations. But high cost of these products and concentration on statistically solid risk management techniques (e.g., normal distribution, SWOT-analysis, etc) leave free space to looking for the alternative methods and products, especially in manufacturing.

The primary challenge for quantitative project management is not how to find solutions for the managing of complex projects in the difficult and unpredictable environments (though this is a very important problem too), but how to manage the most ordinary and simple projects in easy and predictable environments. Without knowing solutions of the problems for simple cases it is simply impossible to find correct solutions for highly complicated cases. From here the high failure rate for complex projects exists. To improve the situation it is required to conduct systematic studies in mathematical modeling of human labor and the creation of a common theoretical framework for analysis and synthesis of projects [16]. This research continues the work on the managing manufacturing projects and supporting decision making on enterprises.

1.2. Scope of the research

The scope of the thesis has to be formulated to set bounds to an area of the research. Scope and object of the research: SMEs in manufacturing (particularly, a machine building) industry with little/medium level of automation, where a plenty of work are performed by hand. These enterprises are engaged in small-volume production with make-to-order (MTO) policy, where any automated production lines are excluded. The range of products is varied widely; therefore they prefer an organizational form that is based on (multi-) project management framework. The results of the research are mainly oriented on shop-floor operations management with the concentration on the tactical planning.

1.3. Aims of the research

The aim of this research is finding new approach for rapid planning and assessment of parameters for the case of MPM. Also to work out the method and principles towards the maximum utilization of existing resources within a separate manufacturing enterprise taking into account current obstacles in MPM environment.

In order to approach these aims a few activities should be fulfilled:

- Study different methods that deal with project complexity.
- Find new aspects of the successful management of multiple projects.
- Describe a proposed methodology on the basis of existing theories and practices.
- Perform the computational experiment by using available software to appreciate effectiveness of the selected methodology.

1.4. Structure of thesis

This research is organized in the following sequence (Fig. 1.1). The introductive section shows the importance of the selected research problem. The main target, tasks and scope of the research are formulated.

The second section provides a state of the art in project management theory and practice. MPM is emphasized as a contemporary and worth-promising way of executing business in the manufacturing field. The definitions of program and portfolio are presented. Along with consideration of problems in MPM the great attention is put on the notion of complexity in it. Various types and measures of complexities are showed with a thorough literature review. Author argues that MPM has to be characterized as a complex system. Some features from the complexity theory are discussed with regard to changing research paradigm (from Newtonian/reductionism to chaos/complexity). The latter is applicable to the MPM context. In the conclusion of this section three positive hypotheses are formulated.

Third section is totally dedicated to the theoretical and methodological grounds of the research. Fractal theory is mainly used for the approach proposed in this thesis. The idea of B.Mandelbrot of self-similar entities in whatever structure is conceptualized for the application in MPM environment. Depth-looking sight in activities (i.e., labour tasks, single works) of projects provides a novel approach to planning and executing of projects in manufacturing SMEs. Basic algorithms of the approach are explained and illustrated. The author also pays his attention to the effect of self-organization in human management within

MPM. Theory of entropy (i.e., mutual information) enables to calculate a measure of self-organization in a project team. Theory of gradient may be implemented to the planning and controlling of human efforts application in order to minimize duration and/or staff size. Performance of projects and post-mortem analysis are realized through the application of self-organizing maps (SOMs).

The final section of the thesis demonstrates the application of the abovementioned methods. The case-study is performed in the small Estonian manufacturing enterprise. The main results and approval of the stated hypotheses are presented in the thesis conclusion. Of course, this study is also contributing some nuances to be explored in the near future.

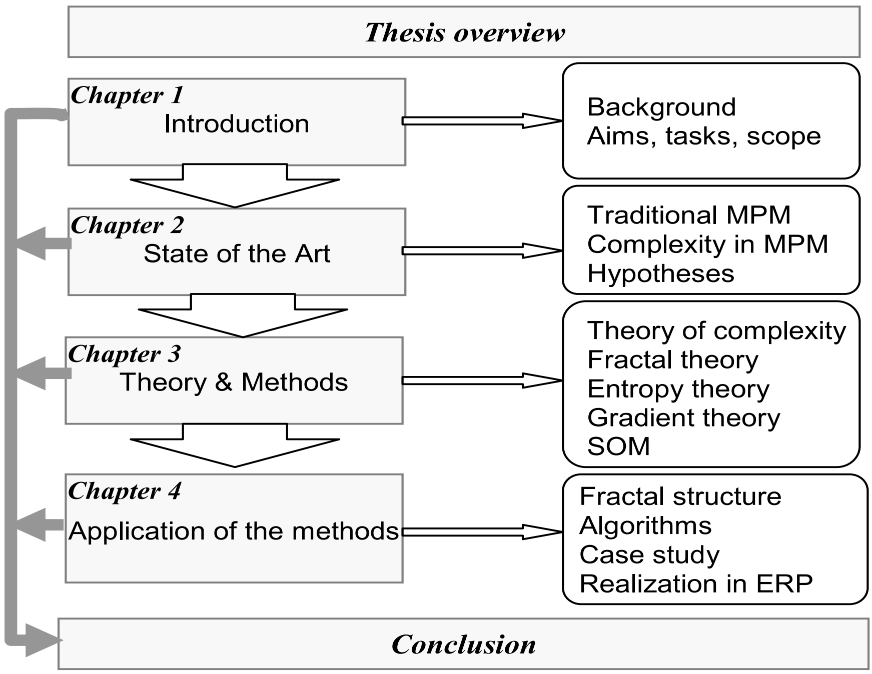


Figure 1.1 Structure of thesis

2. STATE OF THE ART

2.1. Project as a means of the enterprises activity

The present manufacturing companies face an unprecedented process of change in their business environment. Important changes in competition, such as market globalization, shorter product life cycles and product customization, variations in demand patterns and rapid technological developments, the great amount of information and knowledge to be processed call the traditional organization structures into question and require flexibility and reactivity. The prominence of project-based organizations in achieving its tactic/strategic objectives under such severe business conditions was demonstrated extensively [9, 110].

Project management is increasingly becoming a way of life, which is less concerned with routine execution and more concerned with implementing constant change. The great number of manufacturing companies around the world performs their production activities through managing projects. Definitely, the success of performing projects depends upon project manager skills, techniques he/she uses, teamwork and collaboration. Of course, in real-life project situations the huge influence has the working conditions characterized as uncertain, risky, emergence, complex, and unpredictable. Project management theory and its application have been discussed comprehensively through the last few decades. The last edited handbooks summarize the whole bunch of techniques, concepts and methodologies [66, 112, 133].

2.2. From a single to a multiple project management

Managing individual projects is usually a difficult task; the situation becomes much more complicated when there are multiple projects ongoing within an organization. Researchers overwhelmingly concur that general project management literature is heavily biased towards the single project paradigm; however the adoption of the single project management strategies usually provides less benefits for multi-project organizations [17]. In managing multiple projects, it is required to maintain control over a varied range of projects, balance often conflicting requirements with limited resources. Projects need to be managed and coordinated in an integrative manner rather than in a disjointed collection in order to achieve the optimum organizational outcome. The issue of managing multiple projects brings with it a new set of problems that the organization must resolve [40]. Some of these problems are discussed in the following section (2.2.2).

Project is a temporary entity established to deliver specific (often tangible) outputs in line with predefined time, cost and quality constraints. A project should always be defined and executed and evaluated relative to an (executive) approved business case which balances the costs, benefits and risks of the project. The project business case should be managed under change control.

Conventional efforts towards the effectiveness in managing single projects, however, do not suffice in today’s organizations. Project management has not achieved the goals set to it in the present big, complex, and speedy projects; traditional project management is simply counterproductive; it creates self-inflicted problems that seriously undermine performance [71]. Therefore, the managerial focus of firms has shifted towards the simultaneous management of the whole collection of projects as one large entity, and towards the effective linking of this set of projects to the ultimate business purpose [9]. The progress in single and multi-project management over the last decade was studied and concludes that the development and establishment of programs and portfolios as mechanisms for managing organizations has strategic and innovative future opportunities [91].

The single projects are focused on managing risk and obtaining value in accordance with typical project objectives. Contrary, the MPM philosophy of managing projects as programs and portfolios enables the organization to manage risks and derive value in an integrated holistic manner that would not have been possible if the projects were managed as individual undertakings.

Project Management Institute, Inc. (PMI) provides with standard definitions to program management and portfolio management. The exact quotations of both are cited below.

“A program is a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements of related work outside of the scope of the discrete projects in the program. Programs also involve a series of repetitive or cyclical undertakings. Program management is the centralized, coordinated management of a group of projects to achieve the program's strategic objectives and benefits [112].”

“A portfolio is a collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives. The projects or programs in the portfolio may not necessarily be interdependent or directly related. Funding and support can be assigned on the basis of risk/reward categories, specific lines of business, or general types of projects, such as infrastructure and internal process improvement. One goal of portfolio management is to maximize the value of the portfolio by careful examination of candidate projects and programs for inclusion in the portfolio and the timely exclusion of projects not meeting the portfolio’s strategic objectives. Other goals are to balance the portfolio among incremental and radical investments and for efficient use of resources [112].”

An increasing number of companies tend towards an organizational structure in which multiple projects are performed simultaneously. Many companies mostly run a number of projects in parallel that share the same scarce resources [79, 83, 108]. Have to be admitted some factors in which the success of multi-projects differs from traditional single-project management. These factors are:

allocation, division and assignment of resources; prioritization; flexibility; ownership; staff experience, communication, and management style [48].

Table 2.1 Differences between project and program management

	Single project	Multiple project
Objectives	Relatively easy to describe, define and measure.	Difficult to quantify; benefits often based on changes to organizational culture and behaviors.
Scope	Strictly limited; tightly defined; not subject to change.	Not tightly defined or bounded; likely to change during the life cycle of the program.
Duration	Relatively short term; typically 3-6 months.	Relatively long term typically eighteen months to three years.
Risk profile	Relatively easy to identify and manage. The failure would result in relatively limited impact.	Program risk is more complex and potentially the impact on the organization if a risk materializes will be greater relative to project risk.
Nature of the solution	A relatively limited number of potential solutions.	A significant number of potential solutions with disagreement between stakeholders.
Relationship to environment	Environment within which the project takes place is understood and relatively stable.	Environment is dynamic; and programme objectives need to be managed in the context of the changing environment.
Resources	Resources to deliver the project can be reasonably estimated in advance.	Resources are constrained and limited; there is competition for resources between projects.

The following table summarizes the main areas of difference between a project and multi-project (see Table 2.1). Having said about the differences between single and multi-projects, further the attention should be focused on the last, emphasizing its characteristics and challenges in managing them with a rigid mathematical presentations.

2.2.1. Characteristics of the multiple projects

MPM has been largely developed around the following elements: providing a centralized view of all the projects in an organization, enabling a financial and risk analysis of projects, modeling interdependencies between families of projects, enabling prioritization and selection of projects, ensuring accountability and governance at the portfolio level allowing for portfolio optimization and providing support in the form of standardized processes and software tools [7, 38, 46]. The portfolio is dynamically adjusted in response to the arrival of new information, emergence of new project opportunities, completion of earlier projects, or even changes in available resources [82].

The MPE requires an efficient, dynamic process for determining how to allocate resources and set a realistic delivery schedule for new projects, especially when added to an existing set of projects. Besides the problem of scarce resource allocation among the projects and their tasks, one of the important challenges in any MPE is the coordination of the different tasks comprising those projects. Coordination is particularly difficult in situations where the complexity of the comprised projects leads to their division into concurrent, interdependent tasks whose results must be dynamically integrated into an overall portfolio satisfactory solution.

The general lack of research into MPEs has been largely due to the false notion that project principles apply equally to a group as they do to individual projects. They used to be treated as solid projects regardless the idea that MPM is neither an extension nor a scaled up version of single project management.

2.2.2. Traditional problems in managing multi-projects

As projects have become ever more common structures for organizing work in contemporary enterprises, issues involving the simultaneous management of multiple projects (portfolio or programs) have become more pervasive and intense. The problems may include scheduling, coordination and prioritization, resource allocation, and etc [42, 81, 88].

Each project consists of an activity network that draws from common pools of multiple types of resources which are typically not large enough for all of the activities to work concurrently. The goal is to prioritize them so as to optimize an objective function, such as minimizing the delay to each project, or to the overall portfolio. Such is the basic *resource-constrained multi-project scheduling problem* (RCMPSP). Up to 90% of the value of all projects accrues in the multi-project context, so the impact of even a small improvement in their management could provide an enormous benefit. A significant portion of this improvement could come from making better resource allocation decisions [108].

A centralized RCMPSP

$l=2,\ldots, L$ – set of projects,

$i=1,\ldots, N_l$ – number of activities in each project,

d_{il} – duration of an activity (non-preempted),

r_{ik} – unit of resources required to every activity,

$k \in K$ – type of resources,

R_k – renewable capacity of resources,
F_{il} – finish time of activity i in project l,
$(F_{1l}, ..., F_{il}, ..., F_{Nl})$ – schedule or vector of finished times in a project.

The RCMPSP entails finding the schedule for the activities (i.e., determining the start or finish times) that optimizes a performance measure, such as minimizing the average delay in all projects [87].

Objective function:
Let $A(t)$ be the set of activities in work at time instant t. P_{il} is the set of all immediate predecessors of activity i in project l. The problem can be formally stated as performance measure optimization [21]:

Optimize: $$(\forall i \in N_l, l \in L : F_{1l}, ..., F_{il}, ..., F_{N_l l}) \quad (2.1)$$

Subject to: $$\forall i \in N_l, \hat{i} \in P_{il}, l \in L : F_{\hat{i}l} \leq F_{il} - d_{il} \quad (2.2)$$

$$\forall i, l \in A(t): \quad \sum_{i,l \in A(t)} r_{ilk} \leq R_k \quad k \in K; t \geq 0 \quad (2.3)$$

$$\forall i \in N_l, l \in L : \quad F_{il} \geq 0 \quad (2.4)$$

The objective function (2.1) seeks to optimize a pre-specified performance measure (optimal schedule). Constraints (2.2) impose the precedence relations between activities; constraints (2.3) limit the resource demand imposed by the activities being processed at time t to the capacity available; and constraints (2.4) force the finish times to be non-negative.

Some of the popular objectives include minimizing the maximum project makespan (i.e., minimizing F_{max}=max$\{d_1,\ldots, d_l\}$), maximizing the net present value (NPV), maximizing resource leveling, or minimizing project costs (lost benefits).

This problem could be either static or dynamic. In the former problem all projects and their associated activities are known prior to scheduling. The latter one differs by periodic arriving of new projects changing their interdependencies in terms of scheduling and resources distribution. Early efforts in project scheduling were focused on minimizing the overall project duration (makespan) assuming unlimited resources (i.e., CPM, PERT). In addition to resource constraints, there exist precedence relationships among activities of individual projects. This project scheduling problem is NP-hard and most practical solutions that can handle large problem instances rely on priority-rule heuristics and meta-heuristics rather than optimal solution procedures [18, 52].

A decentralized RCMPSP

The dynamics of business means that respond to changes must be made as quickly and as efficiently as possible. The decisions made must be responsive to the immediate needs of the projects; and the process in which these decisions are made must be flexible in order to accommodate for a constantly changing business environment. This environment dictates that the decision making capabilities move away from centralized command and control, and move towards distributing (decentralized type of RCMPSP) the decision-making capabilities to the team in the field. In order to do this, the team in must have full and transparent access to all the information so that the decision can be made quickly and efficiently, while at the same time taking into consideration all the related dependencies.

In particular, it is necessary to determine the schedules $S_1, \ldots, S_n$, such that, in each period $t \in \{1,\ldots,T\}$, the total resource demand by all projects is less than or equal to the resource availability for each local and each global resource, for each project l the precedence constraints A_l are fulfilled, where A is a given set of finish–start precedence relations between pairs of activities. Each project l does not start before its arrival date ($bd_l \geq ad_l$), where bd_l and ad_l – beginning and arrival dates of a project l, respectively; n defines the total number of activities in all l projects. Therefore, a local objective is to minimize the average project makespan M:

$$\text{Minimize} \quad \overline{M} = \frac{1}{n}\sum_{l=1}^{n} M_l \ . \tag{2.5}$$

However, the single objectives of the project are usually at odds with each other. This is the case if activities of different projects require the same capacities of a shared resource $g \in G$ at the same time. In this case the makespan of the projects cannot be minimized simultaneously. Therefore, efficient solutions are sought. To compare alternative efficient solutions of the DRCMPSP, usually an additional performance criterion is used. The most widely used performance measures for multi-project scheduling are:

- Minimize average project delay (APD):

$$APD = \sum_{l=1}^{N} (M_i - CPL_i) / N, \tag{2.6}$$

where CPL_i denotes the critical path length of project i [33].

- Maximize the makespan of multi-project, i.e., the time by which all projects are completed [140],

$$T_m = \max\left\{\frac{W}{R_L}; \max \tau_i\right\}, \tag{2.7}$$

where R_L – constant level of resources; W – work amount in multi-project; τ_i – project criticality level or the ratio of work amount in project to the resource level in it.

In models where due dates are given, performance criteria which minimize total project delay, tardiness, or earliness are suggested by [73, 41, 75, 52]. An additional 'no-time criteria', e.g., minimizing project splitting and maximizing resource leveling are proposed by [83].

Table 2.2 Summary of different subject of research and methods used in MPM

Authors	Subject	Methods
Cohen et al. [31]	Finding the optimal loading point of a finite-capacity stochastic, dynamic, multi-project system.	Cross-Entropy based method
Isakow & Golany [60]	Controlling a constant-work-in-process (CONWIP) in multi-project organizations.	Constant number of projects in process (CONPIP); Constant time in process (CONTIP).
Danilovic, Sandkull [36]	Exploring interdependencies and managing the uncertainty with the information exchange.	Dependence structure matrix and domain mapping matrix approach.
Homberger [57]	Decentralized resource-constrained multi-project scheduling problem (DRCMPSP).	Integration of multi-agent system (MAS) and heuristic restart evolution strategy (RES).
Hans et al. [54]	Multi-project planning under uncertainty that deals with both the complexity aspects of the problem and with the uncertainty.	Hierarchical planning and control framework that serves to position planning methods for multi-project planning under uncertainty.

Certainly, there is not the whole amount of mathematical models being used for MPM optimization problems. A brief summary of objectives and methods used in multi-project problems is presented in Table 2.2. In general they have same features: belong to the class of NP-hard problems, have objective function, and are subjected to a number of constraints. These models may describe different limitations (constraints) imposed in projects, look for an optimal or sub-optimal solution with regard to particular tactic/strategy objectives. Meanwhile, there is a remarkable lack in such optimization models – they do handle with complexity insufficiently. For example, the sequence of activities in projects may vary from time to time, hence any precedence constraints have to be permanently redefined. Interdependencies between activities and projects exist. That makes these models more complex and difficult to be solved.

The following part of the overview is dedicated to study of types and measures of complexity that a manager usually encounters in MPM with. Before the consideration of complexities in project management starts, it is apparent to present a definition of the complexity. There are some definitions of complexity related to projects [56]: consisting of many varied interrelated parts; complicated, involved, intricate; and combination of distinction and connection.

2.3. Complexity in project management

Projects are characterized by complexity (they include many components and dependencies), uncertainty (about resource availability, task durations), dynamic behavior (changes in the scope of the project, adding or removing unexpected tasks, re-scheduling processes) and are inherently heterogeneous (each task may be completed by different resources or in different geographical locations). In the case of a MPE, each one of these features is severely intensified.

Table 2.3 Project complexity vs. dimension model [85]

Project dimensions	**Project complexity**	
	Structural complexity	***Uncertainty***
Project results	Product structure. Multi-objective.	Goal definition. Contextual uncertainty. Familiarity of results.
Project process	Time constraint. Volume of resources. Multiple stakeholders	Work methods. Operational uncertainty. Project management skills. Risk analysis.

Any project is a complex system with a lot of interconnected tasks, number of targets, participants. The nature of the project is characterized as an open system, i.e. interrelations with internal and external environments. At the same time it causes interdependencies among different components of the project in different scales and on different levels.

Traditional project management focused on delivering one project and is primarily concerned with time, scope, and budget. This approach is adequate where there is clarity of scope and certainty. A more holistic approach focuses its view on strategy, change, multiple views and governance. In this view project management must be capable of delivering an emergent strategy while dealing with complexity, uncertainty, change and pluralism. In other words projects are complex evolving systems that can change the rules of their development as they evolve over time [101]. Each project has its own evolutionary strategy and it is not surprising that every project demands an exceptional level of management (because of uniqueness) and usually happens that the application of conventional methods developed have been found to be inappropriate for dealing with complexity in projects.

Table 2.4 Summary of network complexity measures [20]

Complexity measure	Definition/Formula	References
Coefficient of network complexity	$CNC = A / N$, where A is the number of arcs (activities) and N is the number of nodes (events)	(Activity-on-arc), Pascoe [107]; (Activity-on-node), Davis [37].
Kaimann's modified	$CNC = A^2 / N$	Kaimann [63]
Network complexity	$C = A' / N$, where A' is the number of non-redundant arcs; $A' \leq A$	Kolisch [70]
Total activity density	$T = \sum_{i=1}^{N} \max(0, P_i - S_i)$, where P_i is the number of predecessors and S_i is the number of successors for the i^{th} node	Johnson [61]
Average activity density	$AAD = T$-density / N	Patterson [20]
Cyclomatic number	$S = A - N + 1$	Temperley [20]
Measures of network complexity	$MNC = g(A - e_1, A - N + 1)$, where e_1 is the number of arcs out of node 1 and $g(\cdot)$ is a monotonically increasing calibration function, determined empirically.	Elmaghraby and Herroelen [20]

Complex systems are never completely predictable, even if the principle how they function is known. Managers should be prepared to deal with the unexpected events that complexity most certainly will bring forth, by as quickly as possible correcting any deviation from the planned course of action. To achieve this kind of error-based regulation they should not try to predict or determine the behavior of a complex system, but to expect the most probable possibilities. This will make easier to adapt when things go off-course [49].

2.3.1. Types and measures of complexity

One of the first studies where the project complexity mentioned was presented by [11, 64]. In summary they suggest that:

- Project complexity helps determine planning, coordination and control requirements;
- Project complexity hinders the clear identification of goals and objectives of major projects.
- Complexity is an important criterion in the selection of an appropriate project organizational form.

- Project complexity influences the selection of project inputs, e.g. the expertise and experience requirements of management personnel.
- Complexity is frequently used as criteria in the selection of a suitable project procurement arrangement.
- Complexity affects the project objectives of time, cost and quality. Broadly, the higher the project complexity the greater the time and cost.

Table 2.5 Summarizing table of project complexity results

Authors	Subject of consideration	Conclusions
Camci and Kotnour [23]	Measures for assessing project technology complexity and management style	Project technology complexity consists of product & methods (processes, tools, techniques) complexities.
Williams [138]	Structural complexity; relationship between complexity and uncertainty	As the project develops, the uncertainty and hence complexity is reduced. Affects lack of information.
Baccarini [11]	Organizational and technological complexity	Both are based on differentiation and interdependency.
Maylor [90]	Resource complexity	Project members or activities increase the project complexity.
Murray [97]	IT project complexity	Project size and length complexity affect the risk of failure.
Clift and Vandenbosch [30], Lebcir [74]	Complexity and development cycle time in NPD projects.	The more complex the project, the more participative a leadership style. Project complexity has negative effect on cycle time.
Halpern [53]	Complexity in NPD projects	Complexity arises in timing, focus, interoperability and collaboration, dependencies and interactions between project elements, and resource constraints.
Nobeoka and Cusumano [100]	Design and technology transfer among multi-projects; task sharing in NPD	Project task complexity influence upon lead time and engineering hours; comparison of various multi-project strategies finding the best.

There are two dimensions: organizational complexity and technological complexity, which could be specified by differentiation and interdependency. Organizational complexity based on differentiation can be either vertical or horizontal. Vertical differentiation is the depth of the organization's hierarchical structure. Horizontal differentiation is determined by the number of organizational units and the task structure i.e. division of labour and job specialization. The other attribute of organizational complexity in projects is the degree of operational interdependencies and interaction between organizational elements [11]. Technological complexity by differentiation is determined by the variety or diversity of inputs, outputs, tasks, number of specialties involved in a project, etc. Technological complexity by interdependency is in turn determined by interdependencies between tasks, inputs, technologies, teams etc. [11]. Another model of project complexity versus project dimension is presented in Table 2.3. Many network complexity measures have been proposed during last few decades in different contexts and project types. Tables 2.4 and 2.5 review and summarize some of them.

2.4. Two paradigms of the science

In the 20th century, social and management sciences have been dominated by two main scientific paradigms; the Newtonian paradigm and the complexity paradigm. The dominant paradigm in social and natural sciences for the last couple of hundred years has been the mechanistic/reductionistic view based on the teachings of Newton and Descartes. The Newtonian paradigm views the universe and everything in it as a machine. This mechanistic view leads to the belief that studying the parts of the machine is essential in understanding the whole [19]. The Newtonian paradigm has been immensely successful in creating the development in human society past three centuries. But as the world becomes a more complex, interconnected and highly volatile space, the reductionistic Newtonian paradigm fails to understand the whole system for it cannot help focus on the parts of the system [19]. The Newtonian framework does not simply allow seeing the world as it presents itself to us. Reductionism allows complex phenomenon or systems to be structured into, respectively, spatial and temporal hierarchies. This structuring provides insight and understanding into the nature and behaviour of complex systems. The complexity paradigm has been emerging from the scientific domains of quantum physics, theoretical biology, chemistry, and ecology as an alternative to the Newtonian paradigm [64, 86, 111, 115]. It has been explored by social and organizational scientists to understand complex human systems [80, 118] becoming a broad platform for the investigation of complex interdisciplinary situations developing from and including the earlier fields of study known as chaos theory [13]. The totalistic approach which is underlined by this paradigm is against the standard reductionist one, which tries to decompose any system to its constituents and hopes that by understanding the elements one can understand the whole system. Conversely, complexity theory is a science concerned with nonlinear dynamics and open, dissipative systems, without emphasis on hierarchical structure, maintaining self-organization, flexibility, diversification and networks. Complexity theory can be defined as the study of how order and patterns arise from apparently chaotic systems and conversely how complex behaviour and structures emerge from simple underlying rules [50, 136, 78]. This paradigm declares the shift from Gaussian to Pareto distribution (i.e., fat-tails, power law) [93].

2.4.1. Features of complexity in multi-project environment

There is hard ground supposing that MP system may be considered as a complex system. Complex system has multiple interacting elements whose collective behavior cannot be simply inferred from the behavior of its elements [126]. Therefore, MP system may be analogously described by means of complexity theory.

1. Complex systems consist of a large number of elements which in themselves can be simple. Single project consists of a number of tasks; portfolio–does the projects of.
2. The elements interact dynamically by exchanging resources or information. These interactions are rich. Even if specific elements only interact with a few others, the effects of these interactions are propagated throughout the system. It means that tasks and/or projects are usually tied through the input/output chain with each other, and any information change may affect the whole task and/or project.
3. The interactions are nonlinear. There is no confidence that a double change in one project will cause the same change in other projects [29, 116].
4. There are many direct and indirect feedback loops. The application of the system dynamics to project management has been significant, especially in order to understand feedbacks [84].
5. Complex systems are open systems – they exchange information with their environment, where all processes are irreversible. Success of a project depends upon endogenous and exogenous factors, such as market situation with all participants on it, supplier's operability, contractor's prosperity, fund sources credibility and many others.
6. Complex systems have memory, not located at a specific place, but distributed throughout the system. Any complex system thus has a history, and the history is of cardinal importance to the behavior of the system. Under the history in project an experience, skills, and action policies of all participants are supposed.
7. The behavior of the system is determined by the nature of the interactions, not by what is contained within the components. Since the interactions are rich, dynamic, fed back, and above all, nonlinear, the behavior of the system as a whole cannot be predicted from an inspection of its components. The notion of 'emergence' is used to describe this aspect. The presence of emergent properties does not provide an argument against causality, only against purely deterministic forms of prediction. It supports the synergy/cannibalization nature in the multi-project (portfolio) environment [45, 92].

8. Complex systems are adaptive. They can (re)organize their internal structure without the intervention of an external context. Principles of adaptive management are strongly endorsed and actively used in many industries, such as information technology and environmental protection.

Definitely, all these properties may exist or not in the system and may affect on it in a different manner. But few of them appear to be very important in terms of validation of any scientific approach to studying MPE. They are: dynamic exchanging in an open system and nonlinearity. There are several traditional approaches to modeling in dynamic MPE with respect to above discussed complexity properties:

1. Discrete event (linear feedback modeling) and continuous simulation [59].
2. Markov chains (sequence of random variables corresponding to the system state; transition matrices) [72].
3. System dynamics (top-down view, feedback loops, etc.) [1, 65].
4. Agent-based modeling (autonomous rule-based agents) [6].

2.4.2. Nonlinear disciplines and principles

Today the application of nonlinear dynamics can be found in almost every branch of science. It includes systems in which feedback, iterations, non-linear interactions, and the general dependency of each part of the system upon the behavior of all other parts, demands the use of nonlinear differential equations rather than more simple and familiar linear differential equations [43]. Its particular sub-disciplines and key concepts include:

- Chaos theory (deterministic chaos)
- Catastrophe theory (Rene Thom)
- Dissipative systems (Ilya Prigogine)
- Bifurcation theory & strange attractors
- Fractals

However, many important physical systems are “weakly nonlinear”, in the sense that, while nonlinear effects do play an essential role, the linear terms tend to dominate the physics, and so, to a first approximation, the system is essentially linear. As a result, such nonlinear phenomena are best understood as some form of perturbation of their linear approximations. The truly nonlinear regime is, even today, only sporadically modeled and even less well understood [103].

In linear systems, the magnitude of the output y is controlled by that of the input x according to simple equation (2.8) in the familiar form:

$$y = mx + b \tag{2.8}$$

Two central features of linear systems are *proportionality* and *superposition*. Proportionality means that the output bears a straight-line relationship to the input. Superposition refers to the fact that the behavior of linear systems composed of multiple components can be fully understood and predicted by breaking up these components and figuring out their individual input-output relationships.

In contrast, even simple nonlinear systems violate the principles of proportionality and superposition. An example of a complex nonlinear equation 2.9 (e.g., logistic equation in population biology) is:

$$y = ax(1-x) \tag{2.9}$$

For nonlinear systems, proportionality does not hold: small changes can have dramatic and unanticipated effects. An added complication is that nonlinear systems composed of multiple subunits cannot be understood by analyzing these components individually. This reductionist strategy fails because the components of a nonlinear network interact, i.e., they are coupled. Their nonlinear coupling generates behaviors that defy explanation using traditional (linear) models. As a result, they may exhibit behavior that is characteristic of nonlinear systems (self-sustained, bifurcations, and chaos) [77].

2.5. Conclusion of the state of the art

The purpose of this chapter is to overview the current state in project management theory and practice. This chapter gives definitions of project program and portfolio, presents distinctions between single project and MPM. Also MPM problems were considered: schedule optimization with resource constraints in the case of centralized and decentralized management (decision-making). The decentralized problems in multi-project context become more wide-spread. Numerous project managers and stakeholders influence the final decision; various suppliers, vendors and contractors affect the day-to-day situation in this environment. The more decentralized project environment the more complexity it brings with. However, the further investigation will focus on the centralized MPM, where only one person managing projects and the whole organization.

Projects are referred to as interrelated, uncertain and dynamic systems. These aspects create various complexities in the context of projects. The notion of complexity in industry in general and in project management in particular is discussed with types and measures. The main applications of different complexity types in project management are presented in Tables 2.3, 2.4 and 2.5.

Complexity theory provides a new understanding of MPM and therefore should form the basis for a case-study analysis concurrently with traditional single project paradigm methods. Complexity is everywhere and is continually growing, with an increasing pace. It is necessary neither complexity value calculation nor their occasional application for the case of multi-projects, but the development of theories and methods for complexity management that would be used in MPM practice. Meanwhile, complexity theory recognizes the absolute impossibility of accurately predicting the future, particularly at the detail level.

Complexity measures find not much application in MPM practice because of three main reasons:

- Existing approaches in complexity are deterministic (actually, one project could not be twice complex than other just because of their double difference in complexity value; also there is no sense to define complexity value if it would change enormously in a while).
- Low validity and weak inference about the complexity values (say it, 100 units of complexity – what does it really mean and how to use it?).
- It does not correspond to the real complexity in MPM (taking into account interdependencies among projects and possible occurrence of synergy).

Taking into account an exclusive sophistication of reviewed optimization problems and their corresponding mathematical models for a solution explained in the core of this section, I have to make some conclusions. In order to reach the objectives stated in the onset of the thesis I may contend that the proposing method (approach) should posses the following characteristics:

- Sufficient exactness and rapidness of calculation.
- Simplicity of usage and implementation on the spot by a manger or worker, who is not profound in programming and optimization techniques.
- Easiness of adaptability to emerging changes (human makes corrections).
- Low cost of deployment without any supporting means, like separate information system, licensed software, and etc. (In the fourth section the integration of the proposed approach with Enterprise Resource Planning (ERP) system is shown. It was done because of two reasons. First, ERP system facilitates the planning procedure in the case study to get production plans for projects. Second, SMEs have a tendency to use ERP systems in their daily business activities.).

The overview of state-of-the-art opens some of the principal challenges in MPM. Regardless of types and specifics of projects the MPM environment ought to be considered as a complex system. Departing from the assumption that complexity theory is a paradigm which helps express relationship laws in MPM, three positive hypotheses were formulated:

1. It is possible to divide every project (simple or complex) into finite-scale elements with distinct characteristics and to define their interdependencies.
2. MPE is a self-organization system with existence of synergy and emergence.
3. Project containing a great (considerable) amount of operational and statistical information can be more predictable and precisely to analyze by using appropriate software tools.

The following section studies theoretical and practical aspects of the complexity theory in MPM.

3. THEORETICAL PART AND METHODS OF RESEARCH

Managing complexity and uncertainty is perhaps one of the most pervasive and difficult undertakings in managing projects. Understanding their origins and applying appropriate models facilitate the development of solutions or strategies to solve complex problems. Each model and strategy capture different aspects, but only represent a portion of the system's total complexity and uncertainty. Complexity and chaos theories are essentially two sides of the same coin. The focus of both is an emphasis on complex systems and phenomenon that is unpredictable, behave according to unknown rules, and do not lend themselves to reductionist descriptions or deterministic solutions. Further investigation includes some theories and methods closely tied with complexity and chaos, which are believed to be helpful in solving problems in MPM (Figure 3.1).

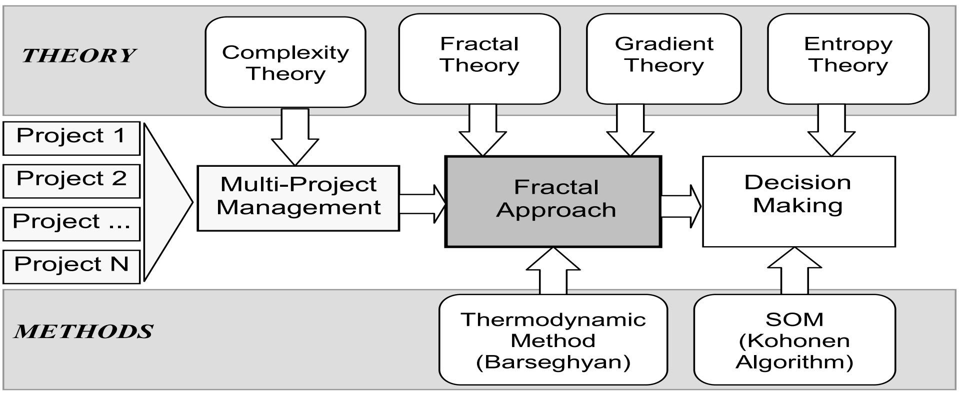


Figure 3.1 Structure of the theoretical research and application

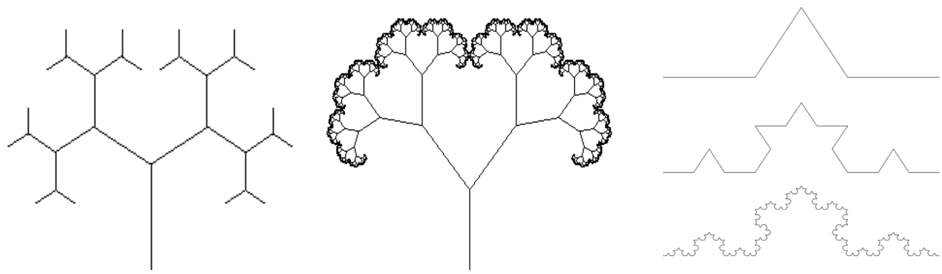
3.1. Theory of fractals

The notion of a fractal came from Benoit Mandelbrot who instilled a new life and added more popularity into the ideas of Karl Weierstrass, Felix Hausdorff and Georg Cantor. His seminal work "The Fractal Geometry of Nature" opens a new vision on the things around us and the nature in general.

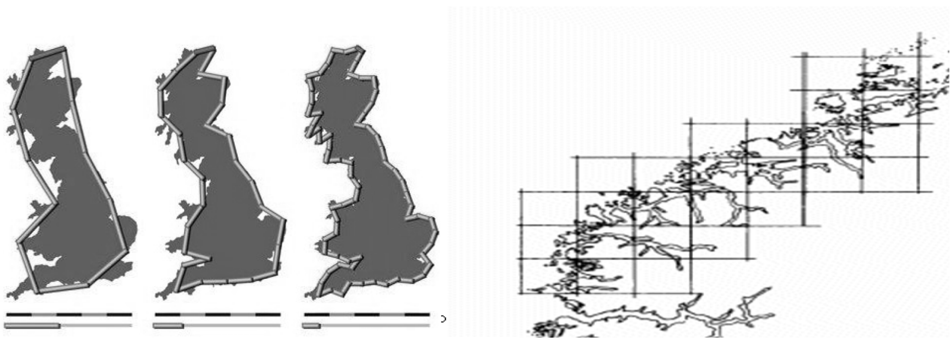
Nature exhibits not simply a higher degree but an altogether different level of complexity. The number of distinct scales of length of natural patterns is for all practical purposes infinite [86].

Mandelbrot coined the term "fractal" to describe systems in which a part is self-similar to the whole, that is, a piece of a fractal when enlarged cannot be distinguished from the original whole. Fractal could be defined as a geometric pattern that is repeated at ever smaller scales to produce irregular shapes and surfaces that cannot be represented by classical geometry. They are used especially in computer modeling of irregular patterns and structures in nature.

Another example is financial records. When looking at a daily, monthly or annual record, one cannot tell the difference. They all look the same. Fractal geometry is an important concept which can be used for qualitative understanding of the mechanisms behind certain processes [86]. Some graphical representations of fractal structures are depicted on Figure 3.2.



a) b) c)



d)

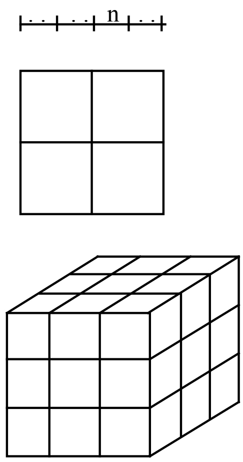
Figure 3.2 a), b) - tree-structure; c) – Koch Curve; d) – coastline of England and Norway

There is no explicit definition on the work fractal; it generally means a complicated scale-invariant configuration. The reversed logic also holds for any power law distribution there is a fractal configuration or a scale-invariant state. Usually fractal is considered geometric concept introducing the quantity fractal dimension or the concept of self-similarity. However, in economics there are very few geometric objects, so, the concept of fractals in economics are mostly used in the sense of power law distributions [130].

A company's size can be viewed by the amount of whole sale or the number of employees. The size distribution of debts of bankrupted companies is also known to follow a power law. A power law distribution can also be found in personal income [4, 102]. Not only money flow data it is very important to observe material flow data in manufacturing and consumption processes.

3.1.1. Fractal dimensionality

Fractals are irregular geometric objects. Taking an object residing in Euclidean dimension D and reduce its linear size by r units of measure in each spatial direction, its measure (length, area, or volume) would increase to $N = n^D$ times the original. This is pictured in the Figure 3.3.



$$N = n^1 \qquad r = \frac{1}{n} = \frac{1}{N}$$

$$N = n^2 \qquad r = \frac{1}{n} = \frac{1}{N^{1/2}}$$

$$N = n^3 \qquad r = \frac{1}{n} = \frac{1}{N^{1/3}}$$

Figure 3.3 The concept of fractal dimension

Generalizing the conception about dimensions the following equation is obtained:

$$N \cdot r^D = 1 \quad \text{or} \quad r = \frac{1}{N^{1/D}} \tag{3.1}$$

Equation 3.2 defines a non-integer quantity called fractal dimension

$$D_F = \frac{\log N}{\log n} \tag{3.2}$$

Dimension D_F need not be an integer, as it is in Euclidean geometry. It could be a fraction, as it is in fractal geometry. This generalized treatment of dimension is named after the German mathematician, Felix Hausdorff. It has proved useful for describing natural objects and for evaluating trajectories of dynamic systems [86].

3.1.2. Fractal and power law distribution

The emergence of power law distributions and other power law dependencies is often associated with fractals and often these power law regularities not necessarily related to geometrical fractals are loosely referred as fractal properties. Power law distributions can be called “scale free” in the sense that the shape parameter is not affected by the standard deviation of the variable. Note that the statistical meaning of scale refers to the variability associated with a variable, usually its standard deviation, and has nothing to do with fractals. Virtually every type of frequency distribution has a *scale parameter* associated with it, but only the power law distribution has a parameter that matches a property of the fractal [12].

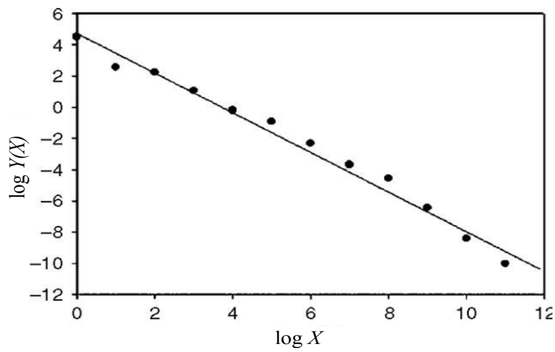


Figure 3.4 Logarithmical illustration of a power law [12]

Mathematically a power law can be generally expressed as:

$$y = ax^k, \tag{3.3}$$

where a is the constant of proportionality and k is the exponent of the power law and both are constants. Because a power law becomes a straight line when expressed logarithmically this can also be expressed as (equation 3.4):

$$\log(y) = k\log(x) + \log(a) \tag{3.4}$$

Simply, in a power law relationship every time one quantity to double the other one is multiplied by a number which is not two, but it is always the same number. The dependencies of quantities in many complex systems have been found to be better approximated by power laws than by linear relationships. A power law is a more general form of relationship and for this reason alone it should be a better approximation.

3.1.3. Fractals in manufacturing design

Manufacturing enterprises are traditionally structured on the basis of labor division. Their structure follows the philosophy of optimization through detailed planning and application of the classical methods of factory focusing on the goal of maximum utilization of the existing resources as regards technical capability and time. The philosophies of the fractal enterprise break with this tradition as they favor self-optimization and self-organization, i.e. the employees themselves are responsible for the layout of the performance centers [99, 135, 137]. Such a type of enterprise implies goal adaptability and similarity at different levels of scale or granularity (fine or coarse) of the enterprise. Fractal enterprise approach considers the enterprise as multi-unit structure on different levels. Each basic fractal unit (BFU) provides services with an individual goal and acts independently. BFU can represent an entire manufacturing shop at the highest level or a physical machine at the lowest level. BFU may have particular basic processes/functions with similar functional input/output structure [58, 120], particular cooperation relationships [24], information flows, and feedbacks, as well as participate in overall fractal workflow (Fig. 3.5). With the theory of complexity they allow to use nonlinear techniques to relate cause and effect in highly dynamic situations through the enterprises [131].

Fractal manufacturing uses the ideas of mathematical chaos: the companies could be composed of small components or fractal objects, which have the capability of reacting and adapting quickly to new environment changes [25].

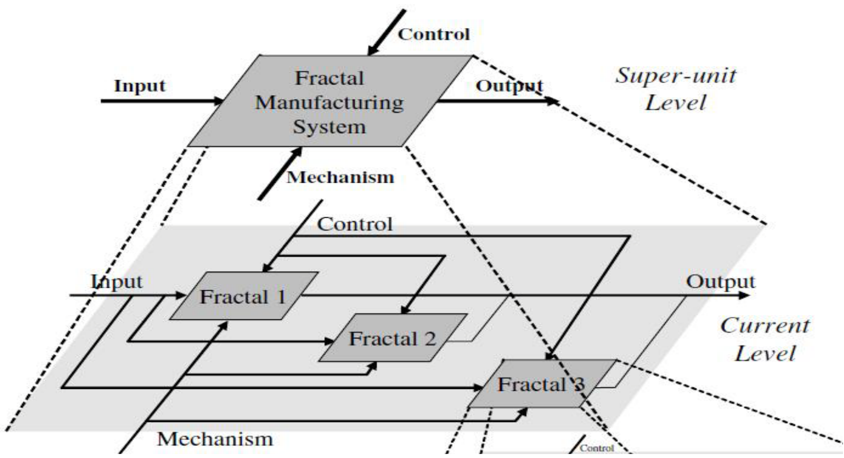


Figure 3.5 Fractal manufacturing system conceptual structure [120]

The features of the fractal enterprise characterize enterprises and other organizational entities such as projects as complex adaptive systems [3, 8, 10, 28, 94].

3.1.4. Fractals in project management

The significance of fractal research (e.g., in the physical science) is that the very idea of fractals opposes reductionism. Fractals are a facet of deterministic chaos, and deterministic chaos is a basic property of non-linear systems, which indisputably exclude precise predictability, even with the best data and models. Fractals present a mathematically well founded alternative to dealing with the problem of scale. Their features are robust as they do not depend on characteristic scale selection.

The principle of fractal view is that a task shapes and repeats structure on the higher level (project, organization). The relationship had originally been established at the level of individual organization units within a firm, but it is in effect a fractal one– that is to say, self-similar at different levels of analysis [86].

Fractal is a modular component model that can be used to design, implement, deploy and reconfigure any project context. It is equipped with a hierarchical structure, and puts an emphasis on reflexivity in order to support adaptation and reconfiguration. They could be more adaptive: they may perform reconfigurations in reaction to changes in their environment. Indeed, when additional ideas or requirements appear during the MPM implementation, new tasks or even projects are being created adapting to changed environment.

The use of fractal approach has been applied in a number of different contexts: manufacturing, physics, biology, artificial intelligence, and etc. [114, 119, 125]. The key to the project-based fractal enterprise is establishing relationships between an "ends-manager" who manages projects and a "means-manager" who seeks to guarantee resource usages as scheduled while maximizing resource utilization over time (in an open market economy) [24, 89]. Principally it is illustrated in Fig.3.6. The fractal enterprise idea is the more appealing one from the standpoint of modeling management tasks since self-organizing and self-optimizing unit characteristics allow more room to differentiate goal management from resource management in SMEs.

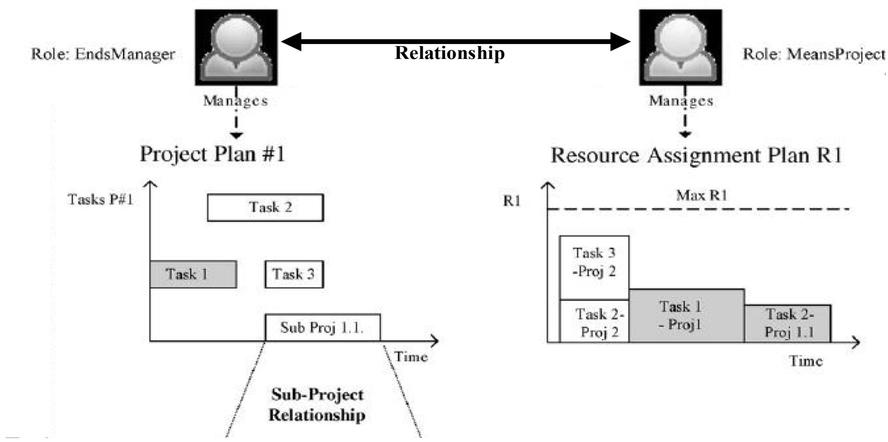


Figure 3.6 Fractal relationships in manufacturing projects [24]

One of the attractiveness of the project-based fractal approach is being a recursive management structure. This structure is both a generator of efficiency and absorber of complexity [123]. Another advantage of the proposed recursive structure is that it naturally lends itself to distributed decision-making [24]. The main characteristics of this approach are: autonomy, goal-orientation, self-similarity, learning, self-organization, and self-optimization. It has to be noted here that to be considered as fractal, the system should not manifest all of these properties [67].

3.1.5. Multi-project as a complex adaptive system

Complex Adaptive System (CAS) is an interconnected network of multiple entities (or agents) that exhibit adaptive action in response to changes in both the environment and the system of entities itself [28, 95]. CAS is a system that overrides conventional human controls because those controls will weaken or even quiet inevitable change and development within that system. Moreover, it is a product of the application of chaos theory and complexity theory to the world of organizations. Organizations that are subject to too much control are at risk of failure [106]. The bureaucracy has been cited as an example of extreme control, and the top down approach to management. However, if a bureaucracy is left to adapt naturally, it could become capable of self-organization and of creating new methods of operating [32].

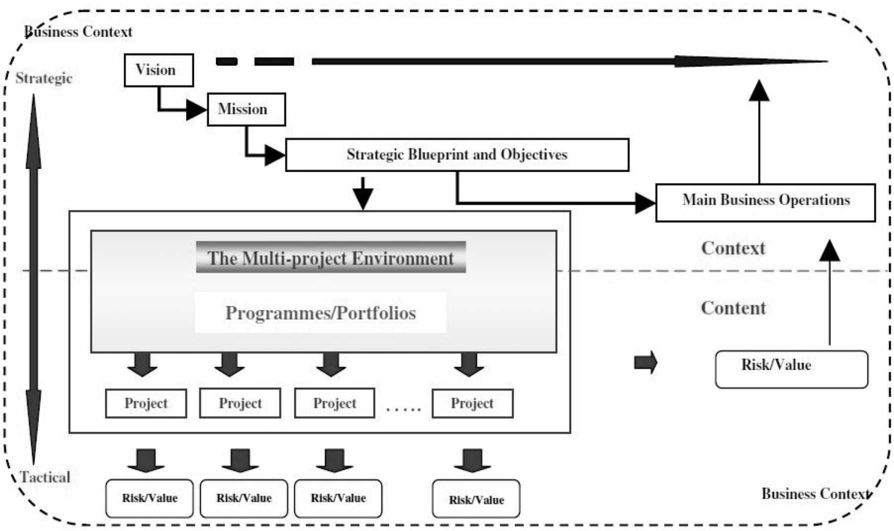


Figure 3.7 System model of the multi-project environment [8]

An increasing number of real-world systems are viewed as CASs. The agents in such systems could present cells, species, individuals, the economy, firms, societies, nations, and so forth [76]. The understanding of them and their interdependencies requires the development or the use of new scientific tools, nonlinear models and computer simulations (e.g., agent-based modeling) [6, 8]. The model recognizes that multi-projects are executed as a means of attaining some business objective and project objective as a means to enhance main business operations or service provision. This business project is undertaken as part of an open system and as such is influenced by the external business environment (Figure 3.7).

3.2. Information theory and complexity

The proposal of this section is to consider the MPM as a process of information sharing (to perform any task within the given constraints) rather than implementation of tasks, where information in projects represent a huge source of complexity and uncertainty in decision-making [44, 51].

Uncertainty, ambiguity, and complexity may be expressed in terms of information inadequacy [26, 109]. Inadequacy of information is caused either by events or causality being unknown (ambiguity), or by an inability to evaluate the effects of actions because too many variables interact (complexity). Considering the information to be almost inversely proportional to the entropy (uncertainty), means to increase the information, through careful planning communication and monitoring the project progress would increase the information available to a project manager. This way, the entropy decreases up to some specific level, so the information could not be absolutely certain and entropy could not disappear entirely. As uncertainty is proportional to risk, decreasing the entropy or increasing the information available, one could decrease unwilling surprises and risks.

3.2.1. The concept of entropy

Entropy measures provide important tools to indicate variety in distributions at particular moments in time (e.g., resources utilization) and to analyse evolutionary processes over time (e.g., technical change). Importantly, entropy statistics are suitable to decomposition analysis, which renders the measure preferable to alternatives [47]. Entropy theory is a good optimization tool which is vital to enhance the effect of preferences concentration for group decision-making [139].

Entropy was used as the measure of the energy expressing the cost of the irreversible associated process (cost of doing business in the reality). Considering control as the work and entropy as its cost, the optimal control problem was reformulated as an entropy minimization problem [122]. Intelligent manufacturing is the process that utilizes intelligent control, with entropy as a measure, in order to accomplish its goals. It possesses several degrees of autonomy, by demonstrating intelligence to make crucial decisions during the process. Such decisions involve scheduling, prioritization, machine selection, product flow optimization, etc., in order to expedite production and improve profitability [122]. This field of research relates to robots and automation in manufacturing where "intelligence" is referred to interaction of human and machines.

Problems of complexity and self-organization have usually been addressed by using the concepts of informational entropy and Jaynes maximum entropy principle [128, 132]. The concept of entropy, a measure of the disorder in a system created as it does work, could explain how linked complex systems interact. Entropy has been extensively used in different fields of science:

- In physics, entropy is a basic concept that measures the "disorder" of a thermodynamical system; any physical system evolves toward maximization of its entropy. Also, the second law of thermodynamics can be formulated in terms of entropy (a tendency of systems to become more disordered or chaotic) [104].
- In information theory, the entropy of a system is taken as the average of self-information; self-information of an event increases as its uncertainty grows. Therefore, the entropy may be regarded as a measure of uncertainty.
- Several maximum entropy methods are commonly applied to one-dimensional stochastic processes (time).
- Possible applications of maximum entropy concepts to the estimation of spatial processes [117].

The uncertainty of modeling complex systems is the reason of introducing entropy. It assumes a stochastic model with uncertain outcome, which is suitable to describe the complex model. Systems composed of many subsystems can produce macroscopic spatial, temporal or functional structures with increasing structure complexities with structures which require an increasing number of parameters in order to be fully described [62]. The property of a complex system may be distributed onto MPEs in whatever enterprise where any sub-projects could create high complexities.

Shannon's (information entropy) measure for uncertainty has been especially used as a measure of dispersion for qualitative data [124]. Suppose there is a set of n possible events (or states) with probability (p_1, p_2,…, p_n). Shannon's measure can be measured by its entropy (equation 3.5):

$$H(p) = -\sum_{i=1}^{n} p_i \ln p_i, \qquad (3.5)$$

where p_i means the probability of some state or event, and the sum is extended over the set of all states or events of any object.

This formula is to be simplified to an example in which there are two events with probability p and q, where q=(1 – p), since the sum of the probabilities adds up to 1. Then entropy in the case of two possibilities with probabilities p and q = 1 is given by equation 3.6:

$$H(p) = -(p \ln p + (1-p)\ln(1-p)) \qquad (3.6)$$

Note that the entropy is never negative:

$$H[p] \geq 0 \tag{3.7}$$

Also note that $H[p] = 0$ if and only if p is known with certainty: i.e., the probability of one outcome is 1 and the probability of all other outcomes is 0.

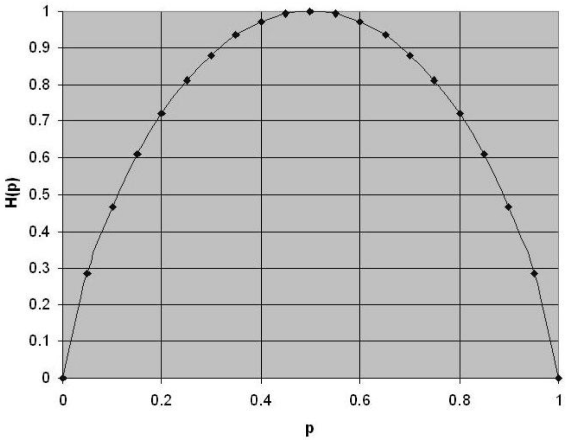


Figure 3.8 Entropy for a system with two states [62]

Graphically the relationship of the entropy and the probability of one outcome may be plotted as in Fig. 3.8.

3.2.2. Entropy in the multi-project management

Multiple projects represent the more complex system than single projects. A systems theory provides the theoretical grounds for understanding multi-projects; systems can be either open or closed. An open system is one which interacts with its environment. It receives inputs and converts these to outputs which are released back into the environment. The environment affects the system through inputs and constraints, but remains outside the system as it does not share the objectives of the system. In contrast, closed systems do not interact with the environment hence producing an isolated and entirely controllable system. Business systems are open systems of interrelated elements working in conjunction with each other in a dynamic and often changing environment.

The key processes within MPE have many complex interactions. Processes are not entirely independent of each other. It is impossible to understand all of the interdependencies. When a new business process is being implemented, usually many simplifying assumptions about other processes that interact with other ones are made. If these assumptions are wrong, usually discover some errors during the implementation and/or control phase(s), and have to make necessary corrections.

Any process, no matter how orderly and well-designed, will degenerate to chaos unless keep adding energy (i.e. information, resources, control actions, etc.). This is the principle of entropy. Many seemingly bright managers appear shocked to find that the gains so painstakingly achieved have disappeared in only a few short years – or even months. Every business process requires energy in the form of controls, redesign, new procedures, additional training, performance measurements and many interventions just to maintain its original level of performance. If want to continuously improve the level of performance, must add even more energy to the system. Practically, entropy is a measure which can indicate the number of unfavorable events in the project [22].

Information in managing projects does not have equal weight. The role of management is to investigate and develop order to reduce uncertainty. Actions of people (in project meetings, reports and other communications) impact "certainty" throughout the course of events, so that some actions can reduce or restrain entropy, and others cause or accelerate it.

An approach of an "entropy theory of project management" is based upon analogies with the discipline of statistical thermodynamics. This is an emergent theory of project management in which the primary objective is to reduce the inherent chaos and uncertainty associated with a project on every life-cycle stage, by the transformation of information into highly structured (i.e., low entropy) products or services.

Multi-project entropy is presented as follows. Each organization has a limit for the total amount of liability that it can undertake. The entropy helps a project manager to calculate the total amount of the uncertainty for all the projects running in his company. Similar to estimating the total project entropy, he/she can summarize entropy of all the individual projects (equation 3.8).

$$S_{MPM} = S_{PRJ1} + S_{PRJ2} + S_{PRJ3} + \ldots + S_{PRJn} \ , \qquad (3.8)$$

where $S_{PRJ} = S_{SC} + S_C + S_R + S_Q + S_S$ are entropy of a schedule, cost, resource conflicts, quality, specifications that are assumed independent. However, this assumption is mostly impossible both for project and even multi-project level entropy [22].

All real-life projects are faced with uncertainty. Uncertainties in the multi-project-driven organization have some main causes: detailed information about the required activities becomes available only gradually (iterative data analysis on a tactical stage), operational uncertainties on the shop floor (operational stage) [54], and strategic forecast in terms of objectives or/and scope of every project in MPM.

3.2.3. Multi-project complexity via entropy

Project A may be in states (A_1, A_2,…, A_n) with probabilities (p_1, p_2,…, p_n) respectively. Project B can occupy states (B_1, B_2,…, B_m) with probabilities (q_1, q_2,…, q_m) respectively. When consider them isolated from each other, have information flow, i.e. influences, changes, etc. (designated as arrows) from the external environment only, without exchanges between project environments (Figure 3.9). In the first example a system is subject to exchange with its environment, not by another subsystem (project). The system is in total exchange with environment and another subsystem in the second case.

Projects A and B are then defined by their respective entropies

$$H(A) = -\sum_{i=1}^{n} p_i \log_2 p_i, \tag{3.9}$$

$$H(B) = -\sum_{j=1}^{m} q_j \log_2 q_j. \tag{3.10}$$

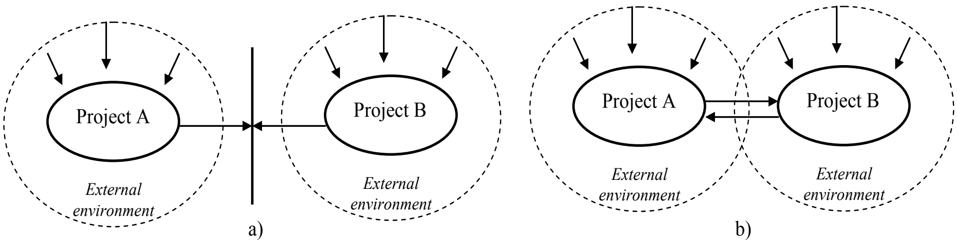


Figure 3.9 Two project system: a) – isolated, and b) – open system

The informational entropy of the isolated system Σ_a is:

$$H(\Sigma_a) = H(A) + H(B) \tag{3.11}$$

For a non-isolated system Σ_b is:

$$H(\Sigma_b) = H(A,B) \le H(A) + H(B) \tag{3.12}$$

The joint (multi-dimensional) entropy of the Projects A and B is:

$$H(A,B) = H(A) + H(B) - I(A,B), \tag{3.13}$$

where *I(A,B)* – the average mutual information entropy measuring how much knowing the value of one random variable reduces the uncertainty about another.

$$I(A,B) = -\sum_{i=1}^{n}\sum_{j=1}^{m} p_i q_j \log_2(p_i q_j) \tag{3.14}$$

According to the second law of thermodynamics, if the system is in the initial state Σ_b then in the absence of any further constraint it will tend to converge to the state Σ_a. Clearly, the system is then disorganizing.

A system would be organizing mainly because there is creation of constraints which causes its informational entropy to decrease. In the same way, it would be self-organizing whenever there is self-creation of constraints. In other words, the level, the grade of the organization capability of the system, would be directly characterized by the constraints which act on it [62].

3.3 Theory of gradients for multi-project parameters definition

Experience in theoretical physics and other sciences has shown that for a complete description of objects under investigation there is a need for both equation of state, and some extreme principles, that reflect their system-level behavior. In this sense the classical example is the equilibrium static thermodynamics with its state equations and extremum principles, such as the minimum energy, maximum entropy and other principles. The rationale of this approach is that the equations of state describe all possible transitions of the system from one state to another, and the extremum principles are choosing one of these transitions only [15, 34, 121].

Since the project management environment is a dynamic system, change management provides the investigation of the functional relationships between project parameters from no change to maximum change, so between various project states. Therefore there is need to consider the gradients of project parameters which are the change directions of a maximum rate. This theory is based on the state equation and the extremum principles that reflect the requirements of a minimum total project effort, minimum risk, etc [15].

Project total effort can be defined as the product of project duration T and project staffing N (equation 3.15).

$$E = N \cdot T \tag{3.15}$$

For change management it is necessary to investigate the directional derivative of the total effort and the direction of its maximum change. The point here is that any change of project parameters can be between zero and maximum change of that parameter in the direction of the gradient. From (3.16) can find the gradient of total effort as

$$gradE = \frac{\partial E}{\partial N} \cdot \vec{i} + \frac{\partial E}{\partial T} \cdot \vec{j} \tag{3.16}$$

For partial derivatives from (3.15) can have

$$\frac{\partial E}{\partial N} = T \quad and \quad \frac{\partial E}{\partial T} = N \tag{3.17}$$

Substituting (3.17) into the expression for gradient (3.16) can have

$$gradE = T \cdot \vec{i} + N \cdot \vec{j} \tag{3.18}$$

From here can find the parametric equation of the effort gradient curve in the project space as the solution of the following two differential equations:

$$\frac{dN}{dt} = T, \qquad \frac{dT}{dt} = N \ . \tag{3.19}$$

The solution of this new differential equation is the projection of the effort gradient curve in the space on the (*T, N*) plane. For the boundary condition (T_0 , N_0) the solution can be presented as

$$N^2 - N_0^2 = T^2 - T_0^2 \tag{3.20}$$

Project space is presented in Figure 3.10. This is the project total effort surface with a project point in (T_0, N_0).

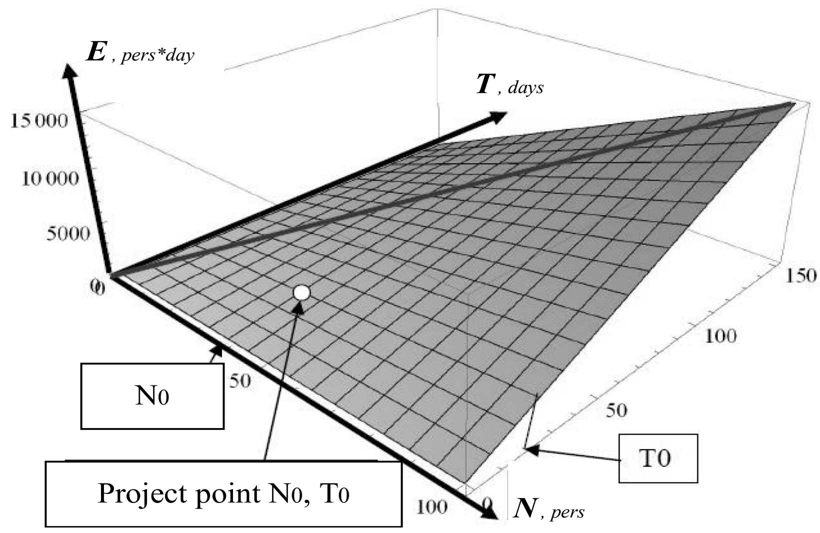


Figure 3.10 Project total effort surface with a project point in (T_0, N_0) [15]

Solving the equation with regard to the average headcount one can obtain the relationship between the level of staffing and project duration for the effort gradient curve.

$$N = \sqrt{T^2 - T_0^2 + N_0^2} \tag{3.21}$$

This expression may be presented in the form of the family of curves (Figure 3.11), characterizing nonlinear dependencies between number of workers in a project and its duration. Practically, even the central line is not straight. Unfortunately, for other cases these curves could not be used, but the equations of functional dependencies [16]. Keep exploring the relationships between parameters, for instance, number of workers and their productivity as a team.

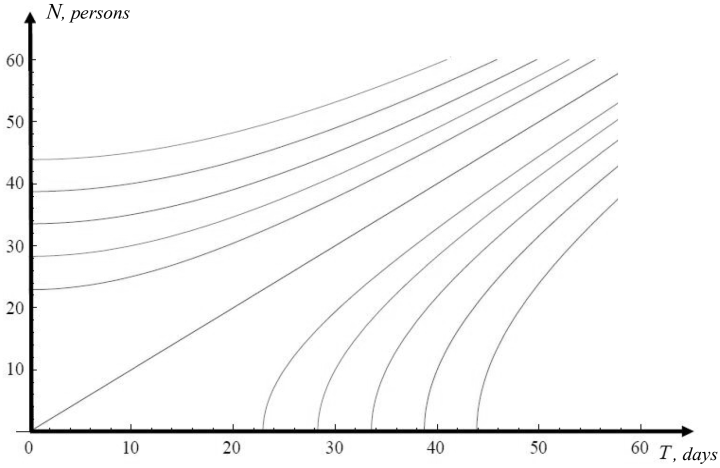


Figure 3.11 Projections of the effort gradient curves on the project's duration and staffing plane [16]

The main conclusion from here is that the definition of project total effort and the extremum requirement of grad*E* are able to generate a family of extreme trajectories or spatial curves that can govern the change management in projects. Requirement of the total effort minimum (E_{min}) is a natural requirement for any project, since it is itself a direct consequence of the minimum expenditure requirement (C_{min}) for the project development. This allows during top-down quantitative analysis of projects to replace the requirement of minimum effort (E_{min}) with more straightforward and geometrically acceptable requirement of the headcount gradient grad*N* (meaning the gradient of the number of working people).

When an enterprise deals with a number of projects the main challenge it is continuously facing is the distribution of a limited number of resources, namely human resources. It may be easy proven that changes in a person's number involved in the project affects other parameters of the project.

To show how it affects let's derive differential equations of an ordinary project using state equation of projects and the principle of staffing gradient. State equation of projects is given by the expression (3.22) from [16]:

$$N = \frac{W}{P \cdot T} \tag{3.22}$$

Changing any of the one of project parameters leads to unpredictable changes in the other parameters. In order to make them predictable let's use the principle of staffing gradient. From expression (3.22) can find the gradient of *N* in the following form:

$$gradN = \frac{\partial N}{\partial W} \cdot \vec{i} + \frac{\partial N}{\partial P} \cdot \vec{j} + \frac{\partial N}{\partial T} \cdot \vec{k} \tag{3.23}$$

Then can find partial derivatives $\frac{\partial N}{\partial W}$, $\frac{\partial N}{\partial P}$, $\frac{\partial N}{\partial T}$ from (3.22):

$$\frac{\partial N}{\partial W} = \frac{1}{P \cdot T}, \tag{3.24}$$

$$\frac{\partial N}{\partial P} = -\frac{W_0}{P^2 \cdot T}, \tag{3.25}$$

$$\frac{\partial N}{\partial T} = -\frac{W_0}{P \cdot T^2}. \tag{3.26}$$

Substituting expressions (3.24), (3.25) and (3.26) into the expression for gradient (3.23) can have

$$gradN = \frac{1}{P \cdot T} \cdot \vec{i} - \frac{W}{P^2 \cdot T} \cdot \vec{j} - \frac{W}{P \cdot T^2} \cdot \vec{k} \tag{3.27}$$

This expression for the staffing gradient can serve as a basis for finding the parametric equation of the gradient curve in the project space.
The functional relationship between team productivity and team size with respect to the number of people *N* in the project can be presented as follows:

$$N = \frac{1}{P} \sqrt{\frac{W_0^2 + P_0^2 - P^2}{P^2 - P_0^2 + T_0^2}}, \tag{3.28}$$

where *N* and *P* are variables.

The functional relationship between team productivity and team size with respect to team productivity *P* can be presented in equation 3.29. The relationship (3.29) is important for a comprehensive understanding of project scaling rules. It is presented in Figure 3.12 in the form of the family of curves.

This equation has also nonlinear dependencies between parameters; therefore the curves are asymptotically decreasing [16].

$$P = \frac{1}{\sqrt{2}} \sqrt{(P_0^2 - T_0^2) + \sqrt{(P_0^2 - T_0^2)^2 + \frac{4(W_0^2 + P_0^2)}{N^2}}} \qquad (3.29)$$

As in the previous example, the shape of these curves may vary considerably. Most important is to obtain the analytical functions of relationships to follow any changes in projects.

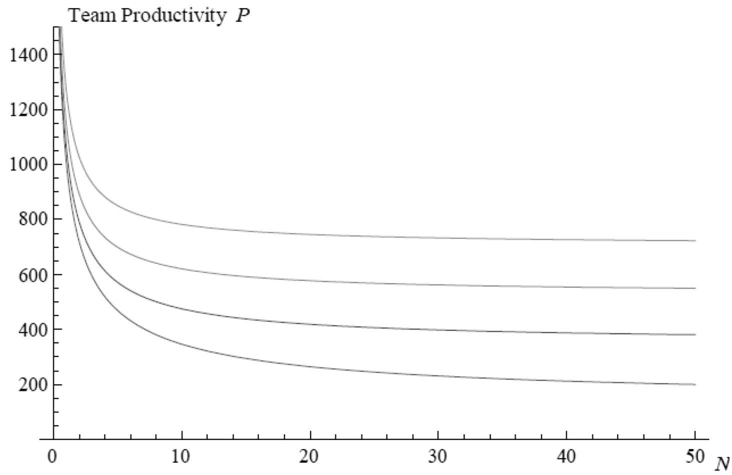


Figure 3.12 Team productivity vs. project staffing level for different constant values of project parameters [16]

Concluding this sub-section, nonlinearities have to be studied constantly, especially in MPM, where tracking changes are extremely important.

3.4. Self-Organizing Map in the project management

Artificial neural networks (ANNs) have been widely applied to various business problems [2, 35, 127, 134], manufacturing processes [27, 129], and project management [5, 105]. ANNs are commonly divided into two main categories: *supervised* and *unsupervised learning* approaches [55]. Supervised networks learn patterns by using target outcomes, and are thus most often used for classification tasks, i.e., where classes are predetermined. Market-driven segmentation would be performed using supervised learning ANNs [96]. Unsupervised learning is used for exploratory analysis, clustering, and visualization. Kohonen introduced the SOM [68].

3.4.1. Kohonen's algorithm

Kohonen's SOM is the most commonly used unsupervised ANN. The SOM is a two-layer feed-forward network, in which each neuron learns to recognize a specific input pattern. Each neuron is represented by a prototype vector, i.e. an *n*-dimensional weight vector. The algorithm is basically a two-step process; in the first step, the best matching neuron (best matching unit) for an input data row is located on the map, and secondly, it and its surrounding neurons within a certain neighborhood radius are tuned to better match (i.e., learn from) the input data, based upon a learning rate factor. The process is repeated until a certain stopping criterion is reached, for example, the training length. The result of the training process is a visual clustering that shows similarities and dissimilarities in the data [69].

The best match, m_c, is found by using the equation in 3.30 [69]:

$$\|x - m_c\| = \min_i \{\|x - m_i\|\}. \tag{3.30}$$

The learning process can be defined as [69]:

$$m_i(t+1) = m_i(t) + h_{ci}(t)[x(t) - m_i(t)], \tag{3.31}$$

where t = 0, 1, 2, ... is an integer, the discrete-time coordinate. The function h_{ci} (t) is the neighborhood of the winning neuron c, and acts as the so-called *neighborhood function*, a smoothing kernel defined over the lattice points.

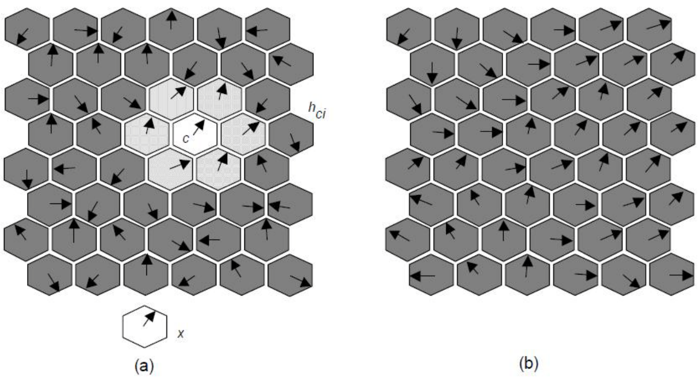


Figure 3.13 (a) A randomly initialized network after one learning step and (b) a fully trained network [68]

The training process is illustrated in Figure 3.13. The figure shows a part of a hexagonal SOM. Firstly, the reference vectors are mapped randomly onto a two-dimensional, hexagonal lattice. This is illustrated in Figure 3.13(a) by the reference vectors, illustrated by arrows in the nodes, pointing in random directions. In Fig. 3.13(a) the closest match to the input data vector x has been found in node c (Step 1). The nodes within the neighborhood h_{ci} learn from node c (Step 2). The size of the neighborhood h_{ci} is determined by the parameter $N_c(t)$, which is the neighborhood radius. The reference vectors within the neighborhood h_{ci} tune to, or learn from, the input data vector x. How much the vectors learn depends upon the learning rate factor $\alpha(t)$. In Figure 3.13(b), the final, fully trained network is displayed.

The most common way of measuring the quality of a map is by calculating the *average quantization error*, Q. The average quantization error represents the average distance between the best matching units and the sample data vectors. The average quantization error can be calculated using the expression 3.32:

$$Q = \frac{1}{N}\sum_{i=1}^{N} \min_{c}\{\|x_i - m_c\|\}, \tag{3.32}$$

where N is the total number of samples, x_i is the input data vector, and m_c is the best matching reference vector.

3.4.2. Self-organizing map in use

Commonly, the SOM software is visualized using the U-matrix (Unified Distance Matrix) of the map, which displays the Euclidean distances between neurons in shades of color. The shaded areas represent different criteria (C_1 , C_2,…, C_{10}) of the model with specific name, i.e., sale year and month, age, price, and etc (Figure 3.14).

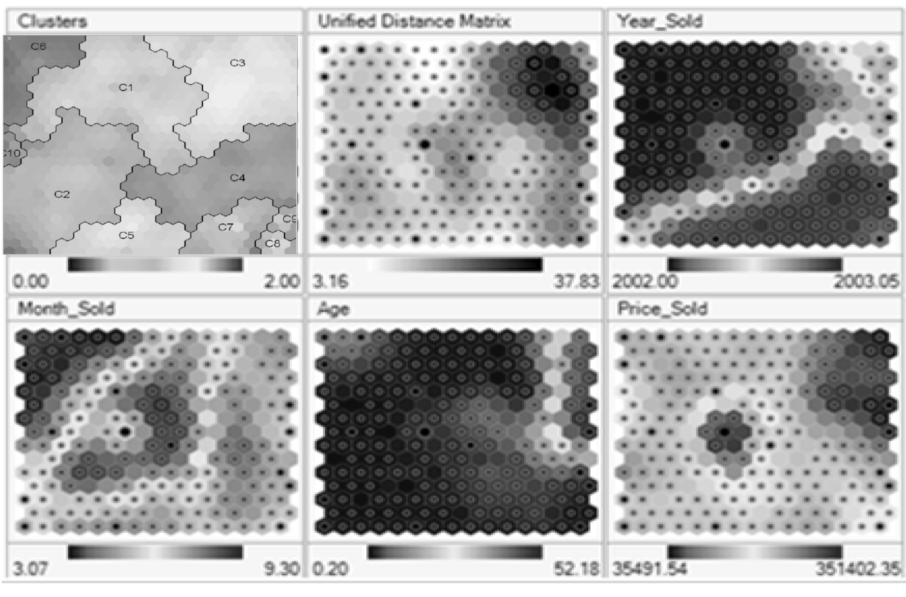


Figure 3.14 Visual representation of the SOMs

For the purpose of the current research the SOM software is employed to map the projects data and information to a two dimensional map. This map can show the on-time projects conditions, parameters, estimate potential risks and opportunities when any parameter changes. These totalistic views facilitate the MPM process. Proposed method can be seen as an element of the risk management procedure [105]. Here the software Viscovery SOMine 5.1 is used. It has found its application in different business areas (insurance, banking and finance, telecommunication, e-commerce) and also in industry for process and manufacturing optimization, system monitoring, quality analysis, and etc.

The SOM has several advantages. Compared to mathematical optimization methods and most statistical approaches, the main advantage of the SOM is that it is a highly visual method. This makes it simple to present and explain results to business decision makers. Also judging the results is more intuitive for a non-mathematically inclined audience. The SOM is also very robust requiring very little preprocessing of the data and unlike most statistical approaches is nonparametric. The SOM is an explorative tool, meaning that very little *a priori* knowledge is required, and it is possible to uncover unexpected patterns in data. Decision trees are simple to use and highly visual approaches, but they are unsuitable to exploratory analysis where no predefined classes exist. Regression approaches and classification-based neural networks are also unable to deal with data when predefined classes are not available [113]. The added value of the SOM is its ability to discover hidden data patterns, structures, and relationships in multivariate datasets.

3.5. Conclusion of the theoretical part and methods of research

This chapter demonstrates the fundamentals of this research. A shift to the complexity paradigm of research has made. MPM is described as a complex system. The underlying viewpoint to the complexity theory is a fractal structure. A number of researchers have used fractal approach for the description of manufacturing systems and project management.

Realizing the apparent advantages of the mentioned approaches as strong analytical capability in modeling and simulation they lack some practical resilience and transparency, ability to view things holistically. To overcome these weaknesses in managing dynamic multi-project system an idea of fractality was presented. Fractal approach organizes the complex system that can be generated through the iteration and integration of the simple units and the common control rules. Fractal system possesses some advantageous features:

- Self-similarity (in terms of modality, information, function or time, etc.).
- Simple, recursive and iterative structure (most needed features for MPM).
- Adaptability and self-organization (finds popularity in rapid exchanging environments with high competition).
- Possibility to describe nonlinear systems (most inter-relations within a project environment are nonlinear).

- The novel structure based on the fractal idea, which has advantages mentioned above should be conceptualized and described with respect to multi-project utilization.

Theory of entropy as an approach to deal with uncertainty in a pair of interdependent entities; a Shannon's entropy also may be used for sensitivity analysis. The principle of entropy is applied to build a framework of information/knowledge flow in the MPE, where a notion of mutual information is served as a characteristic of self-organization. Within an open system, with a large range of information interdependence, the managing environment becomes more self-organizing.

- The quantitative representation of the self-organization effect due to measure of entropy (mutual information) has to be provided in the following section.

Gradient theory is used as change management instrument to finding functional relationships between parameters of the projects. It could be implemented on different project stages applying any changes from nothing to maximum. In the context of MPM the gradient theory is based on the principles of thermodynamics. Since nonlinear dependencies between parameters are a attribute of the complex system, therefore a gradient approach may be used in order to describe the mathematical model of any complex and dynamic system.

- A simple mathematical model for MPM may be formulated with reference to gradient theory.

An approach for managing risks and analyzing data in the MPE has principles of neural networks. The method of SOM is based on the Kohonen algorithm. Data analysis may be represented visually, allowing decision makers to quickly understand complex correlations and to develop the right strategies and realizations.

- SOM application for the case of MPM should be demonstrated. Diverse parameters to be analyzed and the inference about any dependencies (especially) among them to be made.

The next section will present and demonstrate solutions to the tasks formulated in the conclusion of this section.

4. FORMULATION AND APPLICATION OF THE FRACTAL APPROACH

The project itself as an assembly-like process is often more complicated, parallel and dynamic, and thus more complex than traditional project management envisages. The mistake is the ordered view of the surrounding world. All supplies are believed to be made in accordance with the project's – unreliable – schedule, and all resources such as equipment and manpower are supposed to stand by, waiting for the project's call. And changes will not occur. However, this is not the way the world operates.

The project is a working place for humans and a place for cooperation and interaction, which – because of the temporary character – forms a highly transient social system. In this section the research is focused on human resources and their working time in projects. How do they form working groups, and how does it affect the whole performance of MPM will be discussed below. Moreover, the communication in a project team claims a great attention. The idea of self-organization will be explained and quantitatively demonstrated.

4.1 Fractal structure for MPM

4.1.1 Mathematical model of Fractal Project

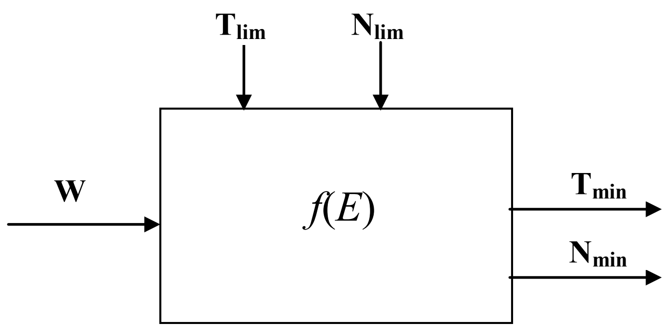


Figure 4.1 Mathematical model of FP

The underlying notion in the fractal project (FP) is effort, E. It could be defined by equations (4.1 and 4.2). Constraints are: project time, which is limited by the contracted due date (T_{lim}), and resources in use (N_{lim}). The latter includes equipment, machines, and staff. Schematic illustration of the fractal is presented in Figure 4.1.

$$T = W / P \cdot N \tag{4.1}$$

$$E = W / P \tag{4.2}$$

where W - is the project work amount needed for the completion of project; P – team productivity [16].

Work amount and productivity may potentially increase and decrease. Therefore, the influence upon the time (T) and team size (N) has to be studied and numerically presented for the case of multi-projects.

4.1.2 Structure of the FP

Fractal approach is based on the assumption that a single activity in the project is the smallest and similar part of the whole project. Of course, projects have various specifications and scope; therefore different project activities may be included in it. Along this case-study a collection of manufacturing projects are in the consideration. An example of the activity is cutting a tube, welding a plate, turning a metal bar, and etc. Exact list of activities for the considered projects may be found in Table 4.1. By the same logic an elementary operation within an activity is a component which is similar to the entire activity; project is similar to the portfolio (Fig. 4.2).

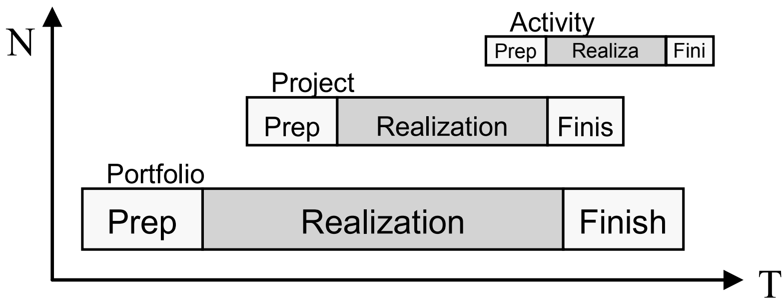


Figure 4.2 Graphical concept of project fractal

Similar feature of these parts (sub-parts, sub-sub, etc) that they all contain three evolutionary stages: preparation ('Prep'), realization ('Realization'), and finalization ('Finish'). Therefore obtain a fractal structure of the project regardless of its size and type. Roughly the fractal structure is illustrated in Figure 4.3. Square of rectangular is proportional to the product of parameters N and T.

Besides the graphical (and abstract) composition of the fractal, mention that it also has valuable contain measured by parameters of time (T), number of people (N), and amount of work or number of finished products (W). These are core parameters presented in [16] as the thermodynamics approach. Depending on the magnitude of these values may build a parametrically scalable picture of a fractal.

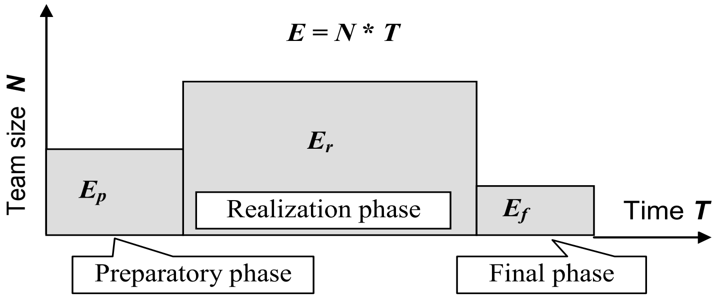


Figure 4.3 Components of FP

$$E_{activity} = E_{prepation} + E_{realization} + E_{finishing} \quad (4.3)$$

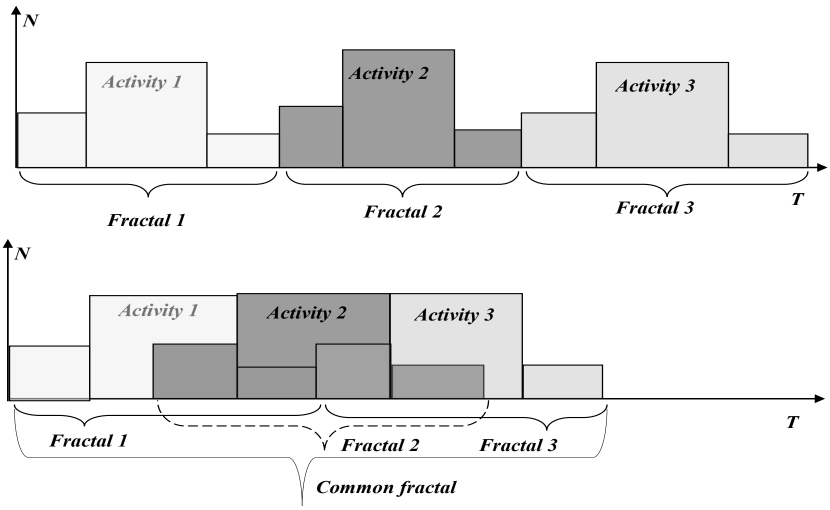


Figure 4.4 Logic of FP combinations

The main part of the fractal, namely *Realization* takes as usual most time of the whole activity. This is the phase, which adds value to our project and product in particular. Other phases, *Preparation* and *Finishing* are non-value-added, but they are needed in terms of technological and production necessities. The former implies processes like detail cleaning, drying, installation and others where the detail is brought into play. The latter is about local enterprise features (e.g. long logistics chain, no painting chamber, etc). Therefore, suppose that ideally all these 0-value processes should be conjugated (or combined) and proceeded during value-added processes (Figure 4.4).

It was said that the main part of the process – *Realization* is performed by a qualified-worker. For instance, if have a milling operation on CNC machine, a machine-operator is a performer. Moreover, this operation has to have some fore and later intermediate operations caused by technological peculiarities of the machine and operation. They are *Setup* (mill installation, CNC programming, etc) and *Wait* (maintenance, cooling down, etc.). In both a machine-operator is involved to due to his responsibilities. Practically every manufacturing (and not only) process has the structure as in Figure 4.5. In other manufacturing processes these operations may be expelled or simply not exist.

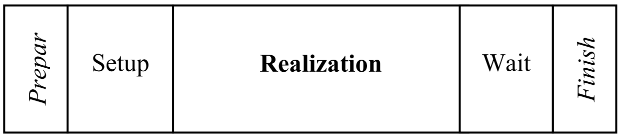
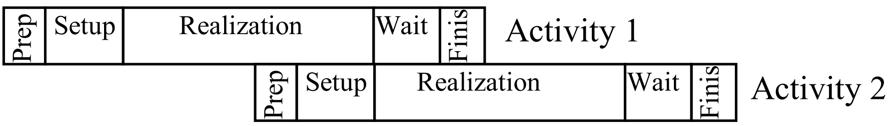
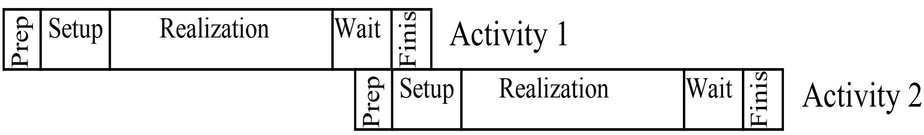


Figure 4.5 Sequence of operations in a single activity

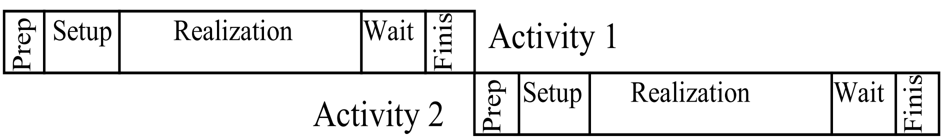
From the other side, *Preparation* and *Finishing* may be carried out by a general worker. He assures the unstoppable movement of details within a manufacturing cycle, assists in a permanent concentration of a machine-worker on his duties. As the result, a general worker is the core person in self-organization incentives across the enterprise, he favours the most efficient utilization of machine resources (machine + operator), and ideally shortens the project makespan. Therefore, some cases of activities' combination exist. The best combination when all non-value-added operations are hidden in value-added operations (Figure 4.6).



a) – work sequence without non-value-added operations



b) – work sequence included only Setup and Wait operations



c) – work sequence included all operations

Figure 4.6 Types of activity combinations

The shape of FP varies due to parameter values. For example, growing number of people in a task makes the fractal taller. In the same time, it gets narrower because of less time to be consumed to finish this task. This idea is presented in Figure 4.7.

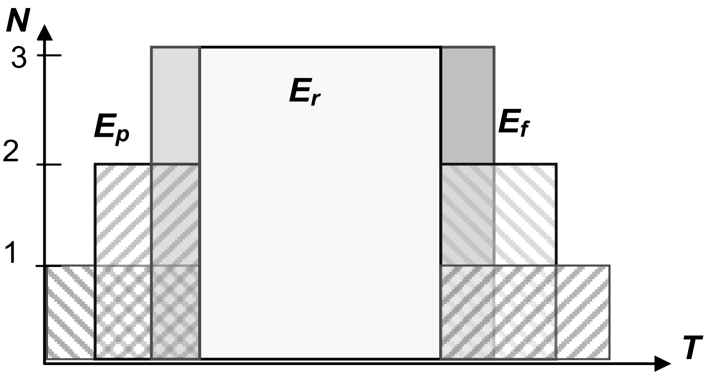


Figure 4.7 Fractal shape changes

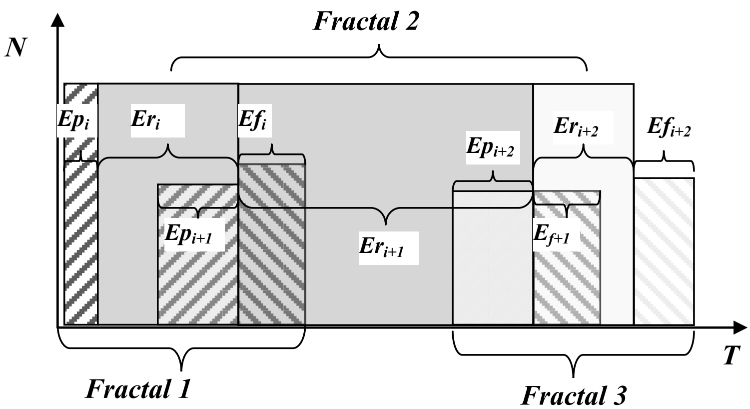


Figure 4.8 FP and their combination

There is a condition 4.4 that should be taken into account when combine a consequence of project fractals. The ideal situation when have all non-value-added processes in the body of value-added processes. This case is depicted in Figure 4.8.

$$T_{ri+1} \geq T_{fi} + T_{pi+2} \tag{4.4}$$

There are two consecutive activities performed on a single resource place or by one worker (e.g. welder). The reduction of the total duration ΔT of these activities may be achieved by adding more workers. Number of additional workers depends upon the targeted time (effort) to be compensated (Figure 4.9).

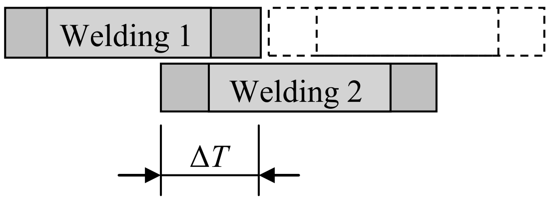


Figure 4.9 Compensation in serial activities

The advantages are as follows: better distribution of activity's main processes, higher performance of the high-qualified workers (welders, turners, etc.), and machines are busy during the value-added process.

4.1.3. Other implementations of FP

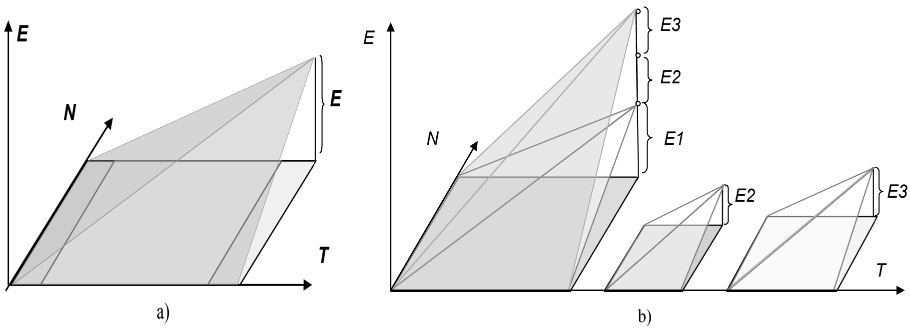


Figure 4.10 Fractal view focusing on grad*E*: a) – single activity; b) – combination of three

Our FP approach may be perfectly connected to the gradient theory (Section 3.3). It allows managing and measuring the dynamics of fractal parameters changes. In order to deal with 3 parameters simultaneously, get the plot as depicted in Figure 4.10. Then propose to consider a project as volume structure. Using gradient theory helps finding trajectory of maximum increase of effort, and hence productivity.

4.2 Algorithm for FP output parameters definition

The project effort and its distribution over time can serve as a basis for the obtaining of the total number of human actions and their distribution over time (Fig. 4.11).

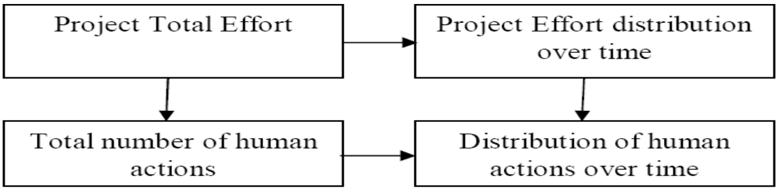


Figure 4.11. Interrelationships between project parameters

From the proposed fractal approach the basic objective is determination of minimal project workers during minimal time of project. The following algorithm is elaborated for that purpose (Fig. 4.12).

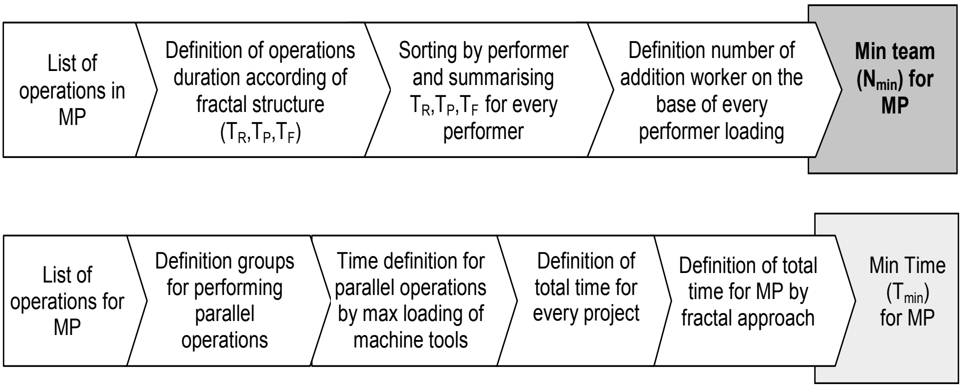


Figure 4.12 Way of N_{min} and T_{min} definition for MP implementation

Sequence determination of N_{min} begins from the tasks description for each project. For every operation must be defined main manufacturing time, preparation and finishing time (T_P, T_R, T_F). For information including is necessary to use electronic tables as Excel, Access for sorting in accordance to different parameters. During the calculation of resource (machine + operator) utilization use the realization time T_R.

4.3 Realization of FP approach

4.3.1 Projects' description for the case-study

To consider the real situation with MPM on a particular enterprise as a case-study of this thesis a local company was chosen. This is a small partnership company of the one of the greatest enterprises in Estonia, namely ABB (Asea Brown Boveri). It specializes in metal constructions for huge equipment in different industries – forest, mining, electrics, etc.

The average number of employees in the company is about 12-14 persons. Two of them are managers. Others are welders, metal-cutters, and technicians.

There are about 3-4 projects in progress simultaneously with an average duration of 6 weeks. The case-study contains 3 projects with a short description about the specifics of each one.

Figure 4.13 Final product of the projects 1 and 2

Project 1 – Spike rollers (Type A, 34 pcs.).
Project 2 – Spike rollers (Type B, 17 pcs.). The produced item is shown in Figure 4.13.
Project 3 – Stator bars, 72 pcs.

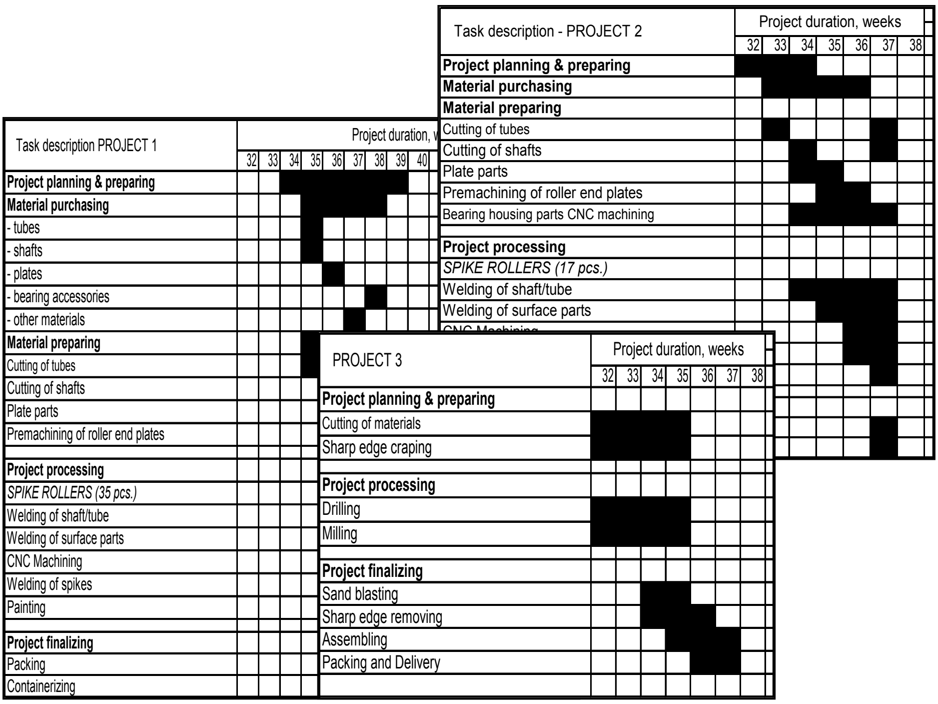


Figure 4.14 Gantt chart for the projects

4.3.2 Calculation

Table 4.1 Basic activities of the projects

Project	Order	Activities	Performer	Time, hours			TOTAL
				T_P	T_R	T_F	
P1	1	Cutting Tubes	Carver	4	16	1	21
P1	2	Cutting Shafts	Carver	4	22	1	27
P1	3	Cutting Plates	Carver	4	16	1	21
P1	4	Machining Tubes	Turner	2	24	2	28
P1	5	Machining Shafts	Turner	2	24	2	28
P1	6	Machining Plates	Turner	2	28	2	32
P1	7	Welding Plat-Tub-Shafts	welder	8	42	2	52
P1	8	Welding Surface	welder	4	16	2	22
P1	9	Welding Spikes	welder	4	16	2	22
P1	10	Machining roller end	Turner	2	18	2	22
P1	11	Assembling	Worker	6	16	2	24
P1	12	Painting	Painter	4	36	2	42
P1	13	Greasing	Worker	2	18	2	22
P1	14	Packing	Worker	4	32	2	38
P1	15	Delivery	Manager	2	6	0	8
Project		Activities	Performer	T_P	T_R	T_F	TOTAL
P2	1	Cutting Tubes	Carver	2	8	1	11
P2	2	Cutting Shafts	Carver	2	12	1	15
P2	3	Cutting Plates	Carver	2	8	1	11
P2	4	Machining Tubes	Turner	2	12	1	15
P2	5	Machining Shafts	Turner	2	12	1	15
P2	6	Machining Plates	Turner	2	14	1	17
P2	7	Welding Plat-Tub-Shafts	welder	4	20	1	25
P2	8	Welding Surface	welder	2	8	1	11
P2	9	Welding Spikes	welder	2	8	1	11
P2	10	Machining roller end	Turner	1	8	1	10
P2	11	Assembling	Worker	3	8	1	12
P2	12	Painting	Painter	2	18	1	21
P2	13	Greasing	Worker	1	10	1	12
P2	14	Packing	Worker	2	16	1	19
P2	15	Delivery	Manager	2	4	0	6
Project		Activities	Performer	T_P	T_R	T_F	TOTAL
P3	1	Cutting of Materials	Carver	2	15	1	18
P3	2	Sharp edge scraping	Carver	1	2	1	4
P3	3	Drilling	Turner	2	16	1	19
P3	4	Milling	Turner	2	20	2	24
P3	5	Sand blasting	Painter	1	4	1	6
P3	6	Sharp edge removing	Carver	1	2	1	4
P3	7	Assembling	Worker	2	8	2	12
P3	8	Packing	Worker	2	4	1	7
P3	9	Delivery	Manager	2	6	0	8

Table 4.1 demonstrates the list of activities of the projects with other parameters. Every activity characterizes any resource's amount of work to finish the project. For example, the welder in the Project 1 has to spend 16 working hours to perform (to weld) surfaces for 34 spike rollers.

Next step – sorting by performer, where from see how much work each performer of the project has to do. Summing this data get Table 4.2.

Table 4.2 Sorted parameters of the projects

Sum of Realization				
Performer	Project 1	Project 2	Project 3	Grand Total
Carver	54	28	19	101
Manager	6	4	6	16
Painter	36	18	4	58
Turner	94	46	36	176
Welder	74	36		110
Worker	66	34	12	112
Grand Total	**330**	**166**	**77**	**573**
Sum of Preparation				
Performer	Project 1	Project 2	Project 3	Grand Total
Carver	8	12	4	24
Manager	2	2	2	6
Painter	4	4	1	9
Turner	8	8	4	20
Welder	16	16		32
Worker	12	12	4	28
Grand Total	**50**	**54**	**15**	**119**
Sum of Finishing				
Performer	Project 1	Project 2	Project 3	Grand Total
Carver	3	3	3	9
Manager	0	0	0	0
Painter	2	2	1	5
Turner	8	8	3	19
Welder	6	6		12
Worker	6	6	3	15
Grand Total	**25**	**25**	**10**	**60**

From here may estimate the amount of work to be distributed among general workers (not specialized workers who work on machines, i.e., turner, welder, carver). This amount is equal to the sum of preparation and finishing times. For example, if have one month (160 hours) to finish all three projects, then it is evident that there is not problems in resources besides the CNC machine resource capacity, since it has 176 working hours (realization total time for turner in table 4.2).

Visual presentation of workloads across all projects is comfortable for a manager distributing non-value-added operation stages among any general workers (Fig. 4.15).

As the result have a minimal team N_{min}. When an enterprise consists of a permanent number of workers, there is a task to distribute workload among typical resources. In this case-study there are 2 welders, 2 turners, 2 carvers.

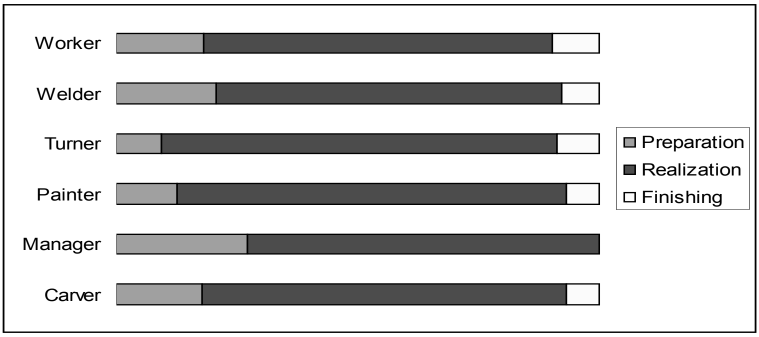


Figure 4.15 Fractals for every performer

Then time of work is decreasing and the fractal changes its shape (Figure 4.16).

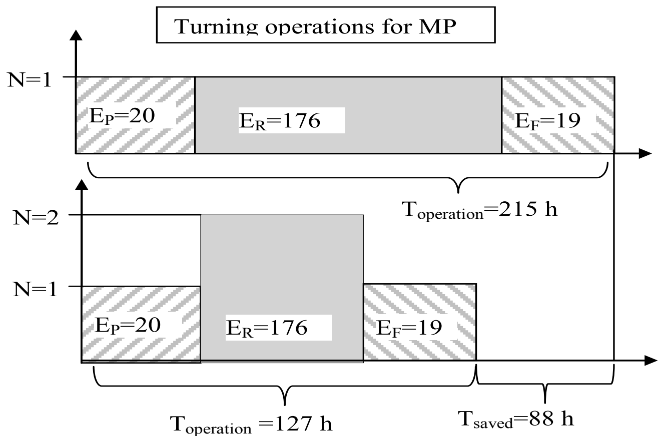


Figure 4.16 Changes in CNC machining operation fractal

Therefore a common distribution of effort among the team member will be as follows (Table 4.3).

Table 4.3 Effort distribution among the team members

Performer	Effort	Persons	Time
Carver	101	2	50.5
Manager	16	1	16
Painter	58	1	58
Turner	176	2	88
Welder	110	2	55
Worker	112	2	56
General worker	179	3	60
TOTAL	**752**	**13**	

Notice that 3 general workers in last row were added and also helped the "Worker" with one more person. So, 4 additional workers are responsible for the total effort of 235 (hour*person). Now it is possible to construct the whole fractal structure for three projects

In Figure 4.17 is introduced sequence of operation of the project 1 by using fractal approach. There are defined work-groups for performing specific works:
WG1 – turning,
WG2 – welding,
WG3 – cutting,
WG4 – painting,
WG5 – others.

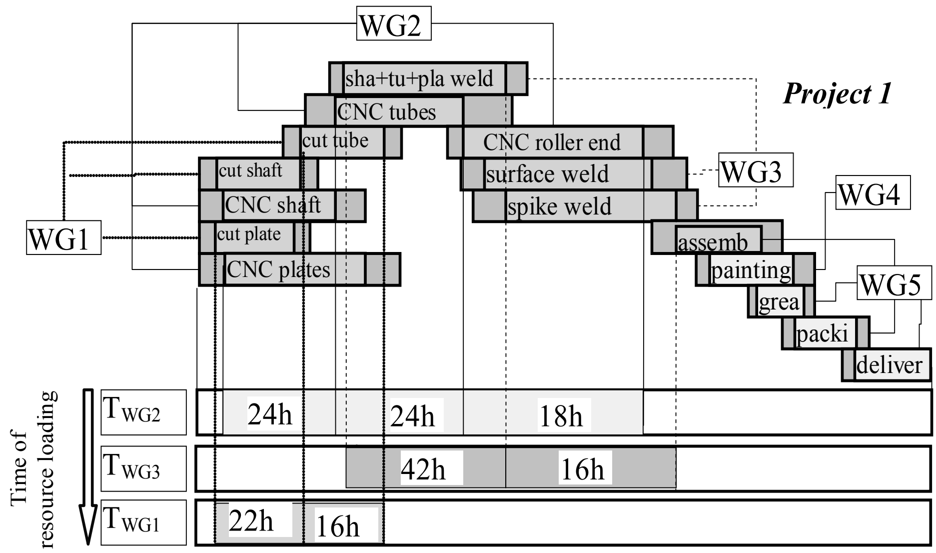


Figure 4.17 Fractal structure for project 1

It is assumed that these assembled fractals visually demonstrate ways of activities combinations, grouping of the concurrent and resource-capacity available operations, definition of the milestones in switching between different projects and different stages. Depending on the established technological routing the total project time may be changed. Duration of a project is limited by the predefined date (usually contracted).

The previous operation sequence may be change and improved due to the grouping of serial and/or parallel resources. The general workers in the project perform the role of chains which connect two processes and which also provide the right information in the right time. Therefore, it may be assumed that is an evident existence of self-organization in a project team. Improved FP obtains more evenly distributed load of resources and gains time savings as well.

The detailed consideration of the self-organization principle follows in the next sub-section 4.4.

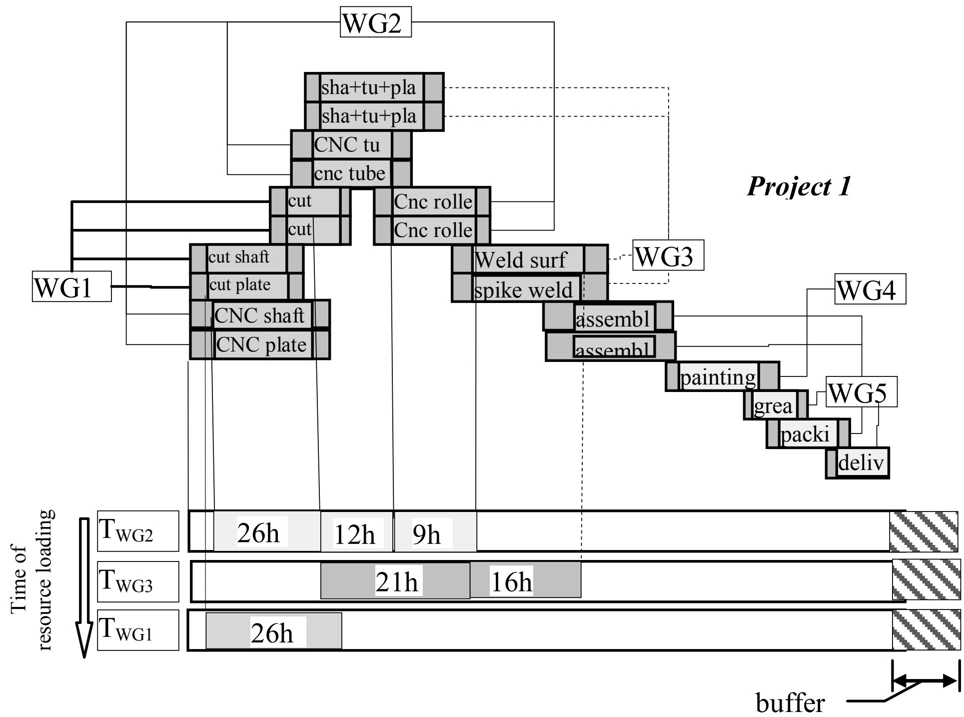


Figure 4.18 Fractal structure for project 1 by using self–organisation in working groups.

After implementing the FP approach a new operation sequence of the project 1 became more structured with apparent working groups ordered in the following way (Figure 4.18). The result is that buffer or saved time has appeared which may be used for planning and execution of the constituent activities in project's critical path. This buffer helps dampen any short delays and leave the project in the desired time scope.

4.3.3 FP approach realization within ERP system

Many industrial enterprises found their competitive advantage by integrating almost all activities with ERP systems (Axapta, Navision, SAP, etc.). They improve qualitative and quantitative measures of business processes, like planning, executing, reporting and collaborating with other partners. So, in this part demonstrate how the FP approach may be used and what benefits it may bring by its implementation in ERP system.

The logic how ERP systems may be used with the FP approach is showed in Figure 4.19. A number of iterations have to be performed in order to receive the appropriate production plan and resource distribution. Additional information from ERP may be obtained: routing list, cost, due dates, and etc.

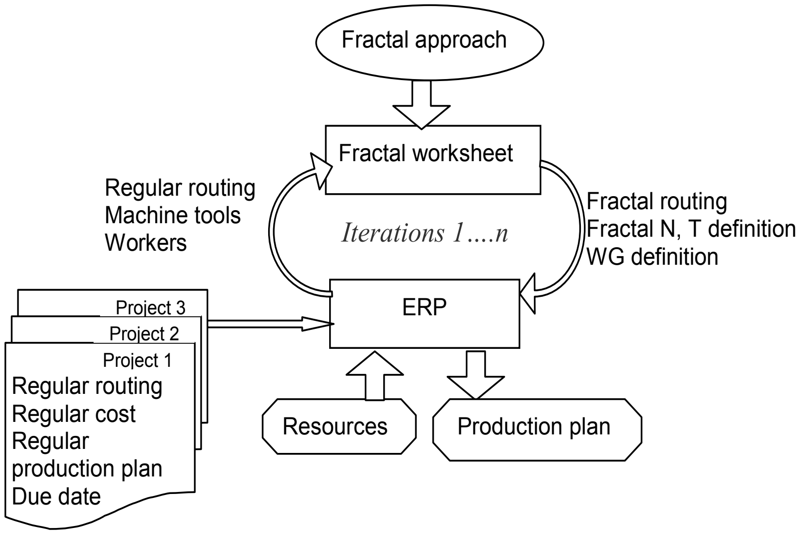


Figure 4.19 Scheme of FP application for ERP

For the case-study MS Navision 4.0 is chosen. Only the first project (Project1) was used as an example. Similarly the approach is fully distributed to other projects from MPM environment. Creation of the item card, and routing list for the Project 1 in ERP.

Operation No.	Next Operation No.	Type	No.	Description	Run Time	Run Time Unit of Meas. Code
5	10|20	Work Center	1	Starting of operation	0	HOURS
10	30|40	Machine Center	1	Cuting shaft	0,79412	HOURS
20	30|40	Machine Center	2	Cuting plates	0,61765	HOURS
30	50	Machine Center	4	Machining shafts	0,82353	HOURS
40	50	Machine Center	5	Machining plates	0,94118	HOURS
50	60	Machine Center	2	Cuting tubes	0,61765	HOURS
60	70	Machine Center	4	Machining tubes	0,82353	HOURS
70	80	Machine Center	7	Welding Plates-Tubes-Shafts	1,52941	HOURS
80	90|100	Machine Center	5	Roller end machining	0,64706	HOURS
90	110	Machine Center	8	Welding Surface	0,64706	HOURS
100	110	Machine Center	7	Welding Spikes	0,64706	HOURS
110	120	Machine Center	9	Assembling	0,70588	HOURS
120	130	Machine Center	6	Painting	1,23529	HOURS
130	140	Machine Center	9	Greasing	0,64706	HOURS
140	150	Machine Center	9	Packing	1,11765	HOURS
150		Machine Center	3	Delivering	0,23529	HOURS

	Name	Work Center…	Direct Unit Cost
1	Carver 1	1	100,00
2	Carver 2	1	100,00
3	Manager	2	100,00
4	Turner 1	4	100,00
5	Turner 2	4	100,00
6	Painter	3	100,00
7	Welder 1	5	100,00
8	Welder 2	5	100,00
9	worker 1	6	30,00

Starting Date-Time	Ending Date-Time
03.10.01 14:12:20	30.11.01 10:17:37

Standard Cost	1 000,571
Unit Cost	1 000,571

Figure 4.20 Routing list with time and cost parameters

Specialist cost 100 EEK/h; Worker cost 30 EEK/h; Material cost is not included. Production order planning and resource usage, production order cost calculation (no materials cost is included). The Resources are described on Machine Center (employee) level and available resources are given in the calendar. Production order view, have critical resource due to restrictions (2 CNC work center, and 2 cutting machines work center).

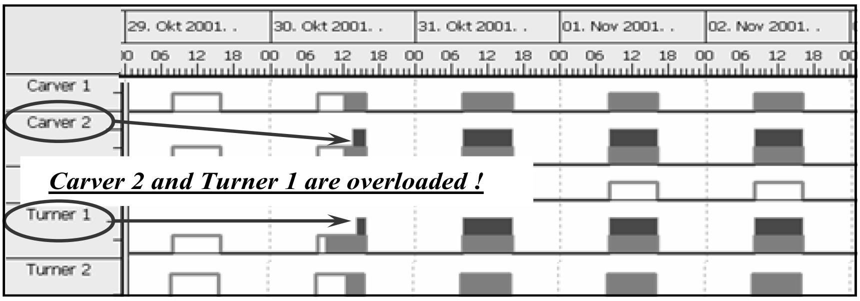
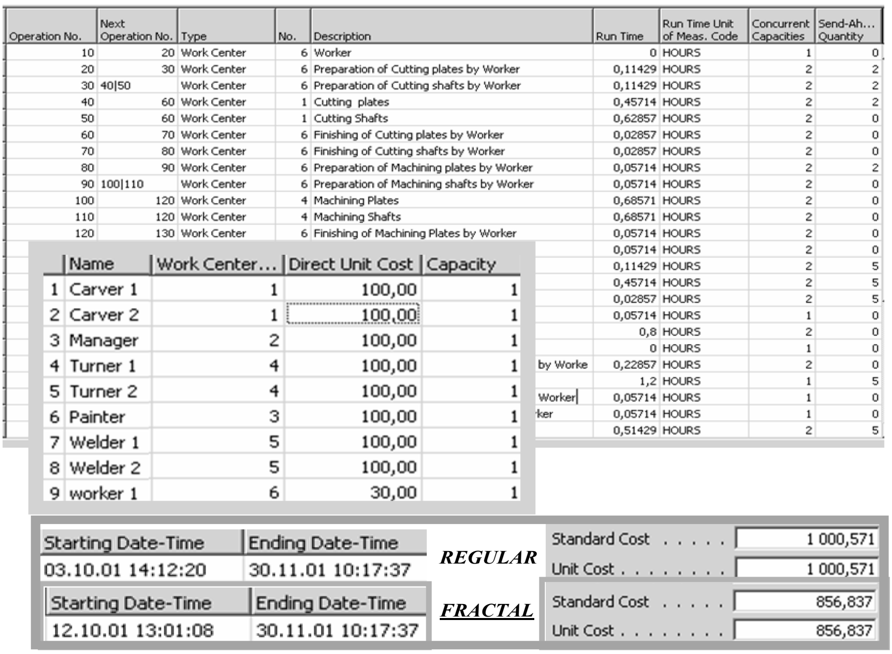


Figure 4.21 Resource allocation in the regular project

The problem appeared with the operation of Cutting and Turning. Then describe them as Bottle necks or Capacity Constrained Resources in ERP system. Critical Load percentage is 90%. And re-plan the Production order. After the fractal approach is used the preparation and finishing tasks in every operation done by specialist are performed by worker.



Operation No.	Next Operation No.	Type	No.	Description	Run Time	Run Time Unit of Meas. Code	Concurrent Capacities	Send-Ah... Quantity
10	20	Work Center	6	Worker	0	HOURS	1	0
20	30	Work Center	6	Preparation of Cutting plates by Worker	0,11429	HOURS	2	2
30	40|50	Work Center	6	Preparation of Cutting shafts by Worker	0,11429	HOURS	2	2
40	60	Work Center	1	Cutting plates	0,45714	HOURS	2	2
50	60	Work Center	1	Cutting Shafts	0,62857	HOURS	2	0
60	70	Work Center	6	Finishing of Cutting plates by Worker	0,02857	HOURS	2	0
70	80	Work Center	6	Finishing of Cutting shafts by Worker	0,02857	HOURS	2	0
80	90	Work Center	6	Preparation of Machining plates by Worker	0,05714	HOURS	2	2
90	100|110	Work Center	6	Preparation of Machining shafts by Worker	0,05714	HOURS	2	0
100	120	Work Center	4	Machining Plates	0,68571	HOURS	2	0
110	120	Work Center	4	Machining Shafts	0,68571	HOURS	2	0
120	130	Work Center	6	Finishing of Machining Plates by Worker	0,05714	HOURS	2	0
					0,05714	HOURS	2	0
					0,11429	HOURS	2	5
					0,45714	HOURS	2	5
					0,02857	HOURS	2	5
					0,05714	HOURS	1	0
					0,8	HOURS	2	0
					0	HOURS	1	0
				by Worke	0,22857	HOURS	2	0
					1,2	HOURS	1	5
				Worker	0,05714	HOURS	1	0
				ker	0,05714	HOURS	1	0
					0,51429	HOURS	2	5

	Name	Work Center...	Direct Unit Cost	Capacity
1	Carver 1	1	100,00	1
2	Carver 2	1	100,00	1
3	Manager	2	100,00	1
4	Turner 1	4	100,00	1
5	Turner 2	4	100,00	1
6	Painter	3	100,00	1
7	Welder 1	5	100,00	1
8	Welder 2	5	100,00	1
9	worker 1	6	30,00	1

	Starting Date-Time	Ending Date-Time	Standard Cost	Unit Cost
REGULAR	03.10.01 14:12:20	30.11.01 10:17:37	1 000,571	1 000,571
FRACTAL	12.10.01 13:01:08	30.11.01 10:17:37	856,837	856,837

Figure 4.22 Updated Routing in accordance with FP approach

By Fractal approach calculates how much workers are needed in particular time period. The product cost is decrease and also the additional resources of specialists are achieved. Production order duration is decreased and resources of specialists are better used.There is final Routing list with cost and due dates (Figure 4.22) for the case of FPs. As see it has much more lines to be filled. This is one of disadvantages in using ERP for fractal approach in MPM.

Multiply project planning and costing is performed for all three projects. The computation experiment is as follows. Today is 02.10.01. At the moment 2 projects are planned:
Project1: Due date is 01.12.01; Total Cost is 34,019 EEK; Project Duration is 08.10.01 – 30.11.01.
Project 2: Due date is 01.11.01; Total Cost is 17,009 EEK; Project Duration is 02.10.01 – 31.10.01.
A new project (Project 3) is coming in with Due date 13.10.01. Estimated cost of project is 9,276 EEK.
To model the production plan for multi-projects ERP is used. Simple calculations propose a plan with the staring date for Project 3 – 27.09.01, which is in the past (Figure 4.23). This shortcoming has to be corrected.

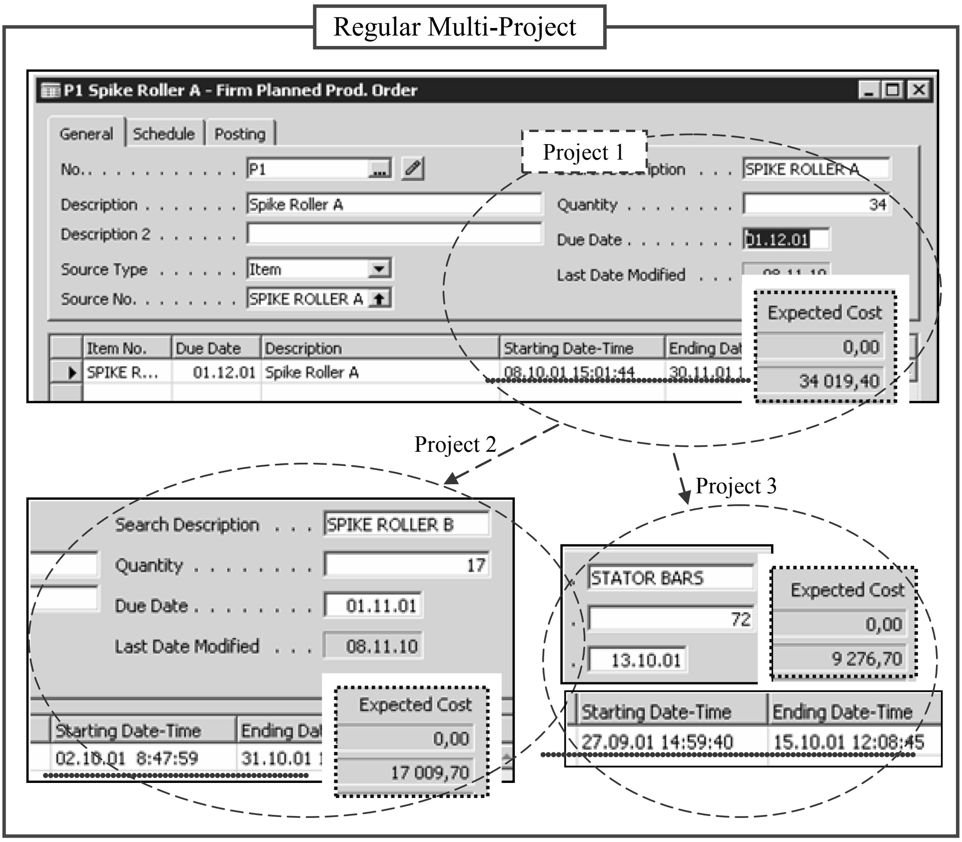


Figure 4.23 Regular production plan for three projects

In order to solve the situation use the FP approach and create the recalculations: Change the Routings of Items SPIKE ROLLER A, SPIKE ROLLER B and STATOR BARS to Fractal and create the recalculations:
Project1: Due date is 01.12.01; Total Cost 29,073 EEK. (Regular routing cost was 34,019 EEK); Project Duration is 15.10.01 – 30.11.01 (Regular routing project duration was 08.10.01 – 30.11.01).

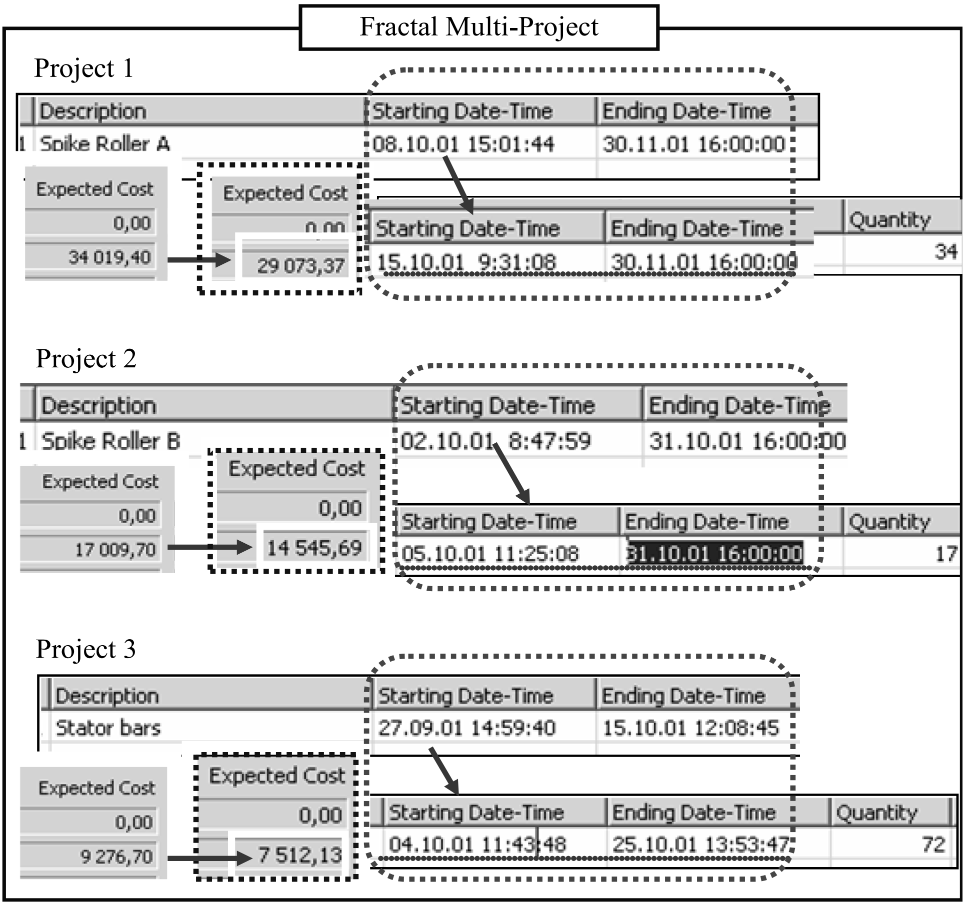


Figure 4.24 Fractal production plan for three projects

Project 2: Due date is 01.11.01; Total cost is 14,545 EEK (Regular routing cost was 17,009 EEK); Project Duration is 05.10.01 – 30.11.01 (Regular routing project duration was 02.10.01 – 31.10.01).
After calculation with FP approach the incoming Project 3: Due date is 13.10.01; Estimated cost is 7,512 EEK (Regular routing cost was 9,276 EEK); Project Duration 04.10.01 – 12.10.01, which is realistic (Regular routing project starting date was in the past 27.09.01). The total ERP plan is presented in Figure 4.24.

The requirements for the integration of the FP approach into an enterprise have to be considered in the following section.

4.3.4 FP approach integration in the enterprise structure

In the previous sections the concept of the fractal approach with its underlying algorithms and examples of implementation with cost/time-based results were demonstrated. Naturally the results of the approach implementation depend upon many factors like projects difficulty and size, capacity of resources (for machines) and their skills (for human), time limits and number of projects, and so forth. But no any result would be achieved without a proper integration of the FP approach to multi-project enterprise. This section specifies the path an enterprise should have overcome to use the proposed approach successfully. This way takes five consecutive steps towards: organization, infrastructure, resources, shop-floor, and projects (Figure 4.25).

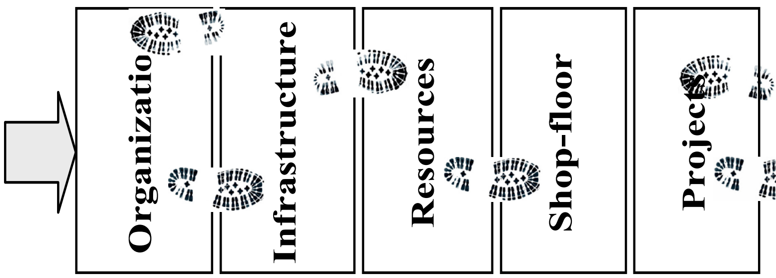


Figure 4.25 Way of FP approach integration in an enterprise

1. ***Organization***. Starting from the top will potentially secure the comprehensiveness and final success of this challenge. Under an organization the governing structure is meant. For the enterprise where one manager, who is also the owner, this challenge may be tackled much easier (the same situation was in the case-study). When there are two or more managers an additional procedure has to be elaborated, since an organization becomes more decentralized in terms of decision-making process (see Section 2.2.2, in particular DRCMPSP). The main aim of that procedure is defining rights and obligations in allocating resources to managing projects.
2. ***Infrastructure***. The FP approach does not require any expensive computational systems. All algorithms and calculations in the approach are designed for the application of electronic tables in Excel. Other software like MS Project and ERP systems may be comfortably used for it (the latter example was demonstrated in the beginning of Section 4.3).
3. ***Resources***. For this approach two types of resource are used – human and machines (and of course, money). Every resource item should be specified correctly. For example, a cutting machine has to be specified along the next attributes: cutting depth (mm), performance or speed of cutting (mm/min), number of workers needed, and etc. Attributes for a

human resource: specialization (cutter, welder), experience (20 years), level of competency (1st-ranked welder in an enterprise inner competition), and so forth.

4. ***Shop-floor***. Diverse aspects on operation level and internal logistics are being in concern. Close to optimal location of machines on the shop-floor provides an efficient value chain creation. Good enough team work performance maintains the existence of self-organization.
5. ***Projects***. That is the point where the FP approach is directly applicable. Presumably by this instant all previous steps are performed. Therefore, the proposed approach and its underlying algorithms may be implemented as a whole.

4.4. Self-organization in the multi-projects

In this part of the research a problem of information management and sharing is discussed. The information presents a notion of growing importance in project management, and especially in multi-projects. In the era of high technologies and internet, the value of information may hugely affect decisions made not only by a manager (receiver), but also managers in collaborative networks. Here the case-study of three projects is presented.

Here suppose that information distribution and hence correct decision-making is available when there is constant connectivity between different parts of the project. In our example number of technological operations is performed by some number of team workers. They all work on their working places separately, like in a cell with partition in terms of up-dated information. For one point of view, it is a good situation because the worker is concentrated on his own work amount and nobody bothers his. But on the other side, it would be an obstacle for the rapid reorganization of his work due to any emergence or urgent situations within a project life-cycle, or a reason of disorder and uncertainty.

Looking forward that general worker who was involved in projects could realize deployment of self-organization capabilities into the MPM. Therefore, a measure of entropy or disorder may be decreased by few general workers who would be sharing information and connecting human resources between each other. Of course, the considerable directing work is preformed by a manager. But in our case do not include his input into self-organization atmosphere in the MPM environment.

The calculation steps are very simple. Use the information only for one project. Step 1: no general workers in Project 1. Total effort is 405. Entropy is maximal (but not absolutely, since realizes that it is impossible).

Step 2: one general worker is added. He brings an effort level of the carver (E_P+E_F) equaled 11. Calculate entropy, mutual information and create plot. And so forth. The results are presented in Table 4.6.

Table 4.6 Efforts in Project 1

	Carver	Turner	Welder	Worker	Remained effort	Shared effort	Remained effort, %	Shared effort, %
No workers	-	-	-	-	405	0	100.0	0
General worker	11	-	-	-	394	11	97.2	2.8
General worker	11	16	-	-	378	27	92.9	7.1
General worker	11	16	22	-	356	49	86.2	13.8
General worker	11	16	22	18	338	67	80.2	19.8

Logarithmic measures of different states and their total entropy is calculated. Results are demonstrated in Table 4.7.

Table 4.7 Total entropy in Project 1

State with additional workers	Number of state	log (remained)	log (shared)	*H* (entropy)
Nobody is added	1	0	-	-
Carver + worker	2	-0.039	-0.141	0.18
Turner + worker	3	-0.093	-0.26	0.353
Welder + worker	4	-0.164	-0.369	0.532
Worker + worker	5	-0.218	-0.429	0.647

Then calculate measures of mutual information *I*(effort), and finally value of self-organization (difference between entropy and mutual information in the project). Results are in Table 4.8.

Table 4.8 Self-organization in Project 1

(remained) * (shared)	log (remained)* log(shared)	*I* (remained * shared)	Self-organization (*H-I*)
0.000	-	-	-
0.027	-5.203	0.141	0.039
0.066	-3.914	0.260	0.093
0.119	-3.075	0.365	0.167
0.159	-2.654	0.422	0.225

The graphical demonstration of the self-organization growth in Project 1 is presented in Figure 4.26. After analyzing it may be concluded that a growth of self-organization has some reasonable limit, because of the existence of hidden nonlinear processes (see section 3 and Figure 3.13 in particular). It is evident that adding workers infinitely (theoretically) into project will give the opposite effect in the end – large project team, low productivity, high labor expenditures. However, definition of the self-organization limit is not a challenge of this work.

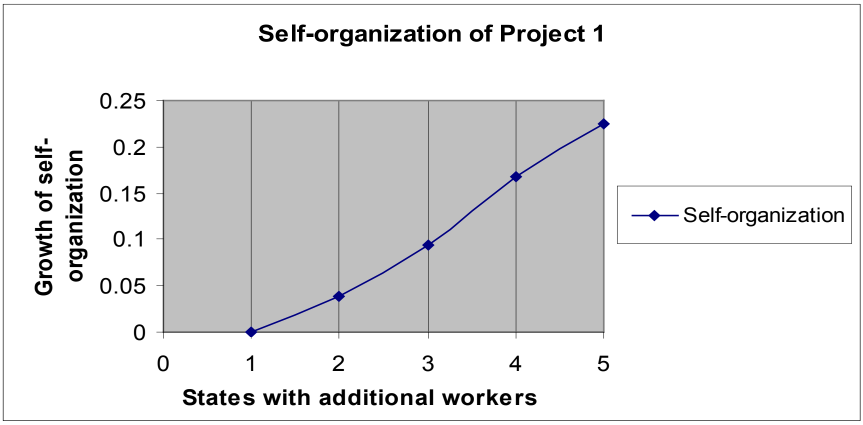


Figure 4.26 Self-organization in Project 1

The total values of self-organization measures in the project are presented in Table 4.9 and plot is depicted in Figure 4.27.

Table 4.9 Self-organization in three projects

	Number of state	Project 1	Project 2	Project 3
Nobody is added	1	0	0	0
Carver + worker	2	0.038	0.095	0.107
Turner + worker	3	0.093	0.196	0.212
Welder + worker	4	0.167	0.319	0.212
Worker + worker	5	0.225	0.399	0.306

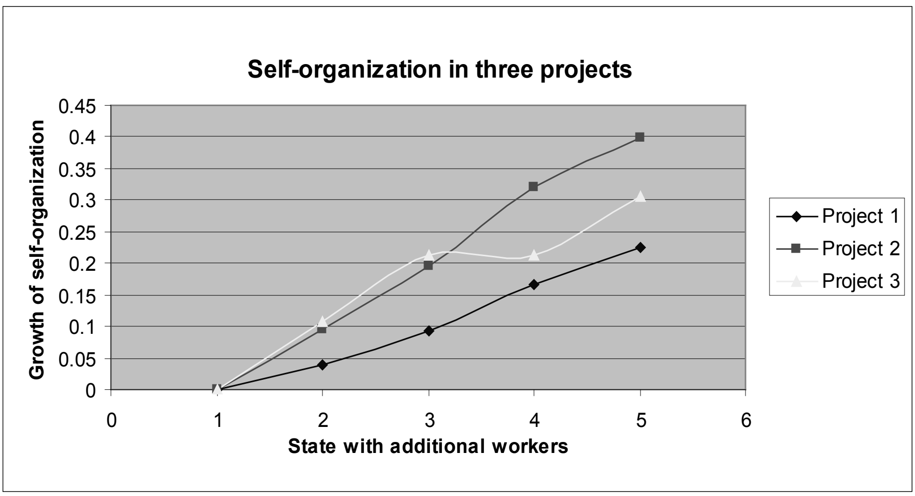


Figure 4.27 Self-organization in Project 1

Concluding the description of self-organization in the projects should say that of course there is no infinite entropy decrease and no any limit point of mutual information. This is mostly because of nature of the process itself. The work is in an open environment, where every time happen switches between certainty and uncertainty. Generally saying, any project management system is always in the non-equilibrium state. Hence, cannot more and more general worker to the project waiting a considerable self-organization growth. As I consider there is an average number of additional workers to be added in the projects of 3 persons.

4.5. Self-organizing maps in MPM

In this section an application of ANN methodology is to be presented. By using Viscovery software it is possible to study any amount statistical information about projects. It is vitally important when have MPM situation with a number of projects sharing same resources. Sometimes it is necessary to define the most preferable amount of products for delivery to customers. To find this sub-optimal batch of products in terms of transportation costs (delay) and production expenditures (duration) may use SOMs in order to visualize the situation for making a quick decision. Statistical information of one of the projects was used (Table 4.10). Here will show how make a reasonable trade-off between time of production and cost for delivery and transportation to select a batch volume of goods.

Table 4.10 Times and costs in the project

Amount, pcs	Transport, Euro	Preparing, min	Processing, min	Finishing, min	Delivery, Euro
1	18	26	47	13	11
5	22	81	135	45	15
16	24	219	537	133	35
20	28	271	665	165	41
30	20	295	985	245	59

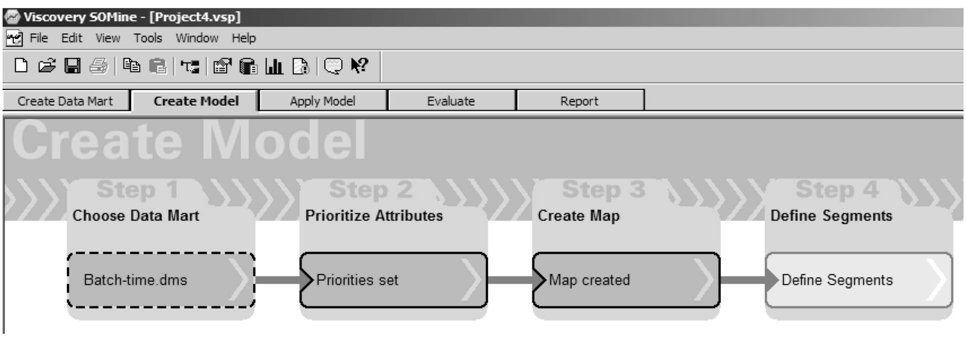
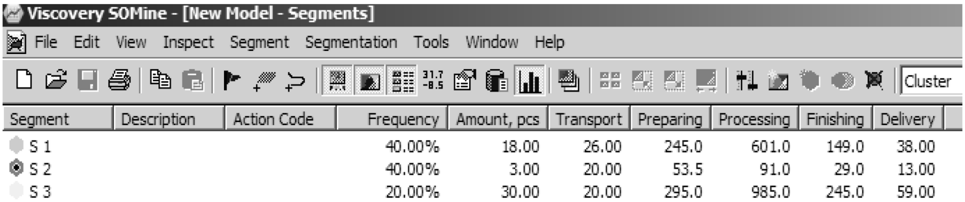


Figure 4.28 Users environment of the Viscovery software

First, import the data into Viscovery software through the solid structure is presented in Figure 4.28. After transforming analyzing data into the software, the algorithm on which it works performs the clustering of data dividing the whole amount of information in to 3 inherent segments with displaying their basic statistical parameters (Figure 4.29).



Segment	Description	Action Code	Frequency	Amount, pcs	Transport	Preparing	Processing	Finishing	Delivery
S 1			40.00%	18.00	26.00	245.0	601.0	149.0	38.00
S 2			40.00%	3.00	20.00	53.5	91.0	29.0	13.00
S 3			20.00%	30.00	20.00	295.0	985.0	245.0	59.00

Figure 4.29 Users environment of the Viscovery software

Upon clustering obtain two-dimensional maps where all studied data is presented in the following form (Figure 4.30). From here may find out some valuable conclusions. Transportation of materials for the project is least costly in the amount of 25-30 finished products. But delivery of the goods to customers is the most expensive in this case, around 55-60 Euro (sections with arrows).

Generally the approach of SOMs could be implemented for a thorough analysis of unstructured and, from the first sight, chaotic data in MPM context to define patterns that would facilitate a decision-making process.

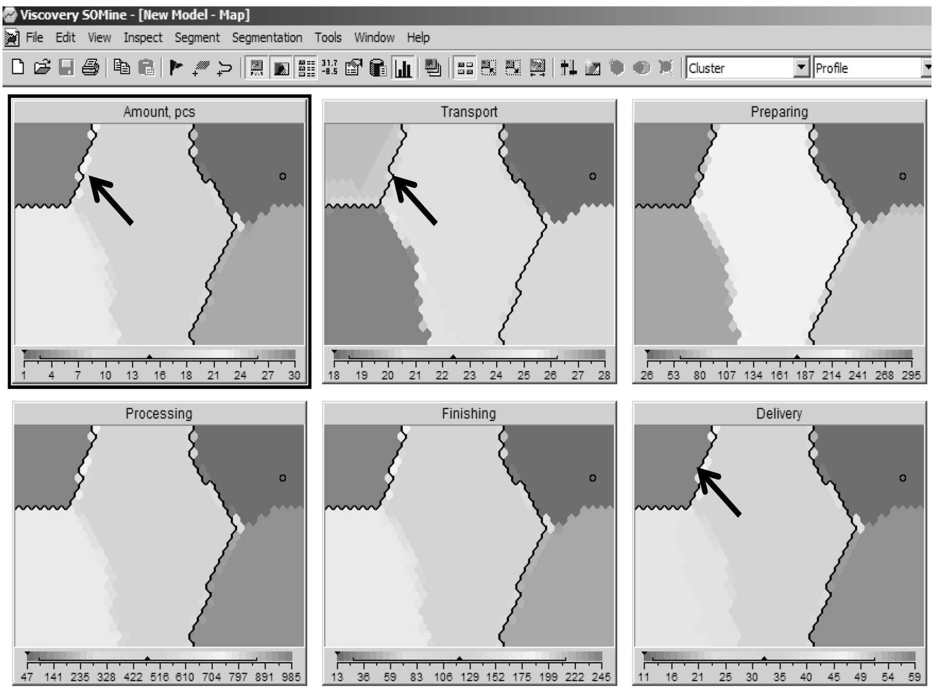


Figure 4.30 Two-dimensional map with analyzed parameters

Analysis results must be represented visually, allowing decision makers to quickly understand complex correlations and to develop the right strategies and realizations. The use of SOM offers an optimal technological basis for predictive analytics. Whenever large amounts of multivariate data sets are analyzed or processed, Viscovery utilizes the power of SOM to manage the data for global ranking or classification. It also supports collaboration during the process of decision-making. It is possible to achieve an unprecedented quality of predictions with such models. Unfortunately, due to commercial restrictions there is no possibility to demonstrate more capabilities of the software and its available usage for the purposes of MPM.

SOMs are presented on-screen in an intuitive way, allowing the user to visually analyze non-linear dependencies in the data without requiring advanced statistical knowledge or reading endless tables of numbers such as correlation coefficients. The visualization of the maps of the data is intuitively understandable for every user.

Recent developments in risk management emphasize the need to carefully assess nonlinear dependence between risks. The nonlinear dependence relates to the whole joint distribution of the variables (not only the first conditional moments) and the main concern is often about the tail of the joint distribution. Different approaches have been proposed in the econometric and statistical literature to describe nonlinear dependence. A considerable attention has been recently devoted to methods based on the joint distribution of the risk variables, such as copulas [98].

4.6. Conclusion of the Formulation and application of the fractal approach

1. Fractal approach enables to distribute resources in an exact time. It shares similar objectives with lean philosophy (Just-in-Time/Kanban production). This fact gives positive characteristic of the FP approach. Multi-scaling structure – the underlying principle used in this study – could embellish a theory of lean manufacturing and improve its practical significance. Meanwhile, the aspect of self-organization realized in the proposed approach benefits any enterprise regardless of whether it deploys lean production technique or not. It also has to be noticed that adding a general worker in MPE would improve synergetic context within an enterprise making it more holistic. The reason is that general worker presents a bearer of self-organization skills.

2. Entropy theory allows to measure uncertainty and complexity in managing projects. As much information is available as much clearer get a picture about projects to be implemented. However, project management remains an intuition-addicted in decision-making process. It means that a human still relies on her gut feeling, previous experience and so forth.

3. Fractal approach for MPM was elaborated and formulated in the previous sections. This is a generalized approach which contains algorithms for calculation purposes. Moreover, and what is more important, this approach is a novel way of thinking, fresh point of view on processes within an enterprise. Proposed FP approach finds relatively easy application in various corporate information systems, in particular ERP. Case-study is presented in MS Navision 4.0. Generally, it shows the reciprocal advantages in combining FP and ERP for the effective resource handling and planning. However, it also revealed some gaps that should be studied for much qualitative and productive co-working of both parts, i.e., long routing list and specific ERP calculus.

4. The case study was presented. The iteration of multi-project data movement from ERP to fractal calculation worksheet and updated data back to ERP system was approved. During this case study the total duration of the projects in multi-project has decreased (totally – 17 days):
Project 1 – 7 days;
Project 2 – 2 days;
Project 3 – 8 days.
The total cost of multi-project has decreased (totally – 9174 EEK):
Project 1 – 4946 EEK;
Project 2 – 2464 EEK;
Project 3 – 1764 EEK.

In this case was verified that the use of the fractal approach enables to decrease the total production time, which gives the possibility to add additional project to existing multi-project and the total cost of multi-project was decreased by 15%.

5. Fractal approach allows "compress" the projects efforts through the better utilization of resources and performers' work-time. This effect can be introduced as Snow-ball (see figure 4.31).

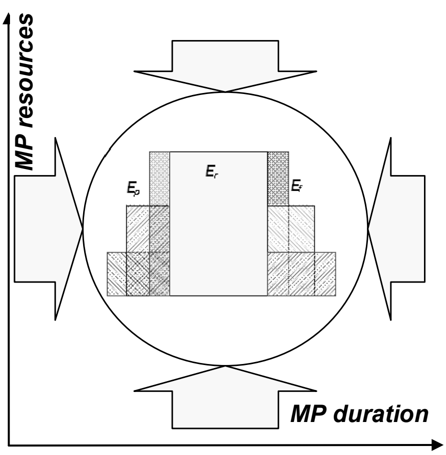


Figure 4.31 Snow ball effect

CONCLUSION

Results

Aim was formulated and decided successfully, the main objective of the work is gained. Basic activities of the work were studied and resolved.

The new approach for achievement of this aim came from assumption that multi-project is a complex system, which is directed by laws of complexity theory and chaos.

In the framework of the thesis the following activities have been performed:

1. Different methods for complexity resolution were considered in Section 2. The notion of complexity in industry in general and in project management in particular is discussed with types and measures. The main applications of different complexity types in project management are presented in Tables 2.2 – 2.5. MPM described with help of complexity theory and its properties were presented (Section 2.4.1).

2. There are several traditional approaches to modeling in dynamic MPE with respect to above discussed complexity properties (Section 2.4.1). However, theories of non-linear dynamics were successfully implemented in other fields of science for decision of complexity. As a main key for resolving our problem were defined theory chaos and complexity, in particular fractal approach. (Section 2.4.2). Theory of complex adaptive systems appeared to have almost the same philosophy in terms of self– characteristics. The main properties of both fractal and complex adaptive systems were presented. The approach of representing multi-projects as a complex adaptive system lacks the sufficient methodology about self-organization.

3. In section 3 theories used in this research were depicted in Fig. 3.1. The fractal approach was theoretically described with its features. Fractal structure for MPM was elaborated with basic parameters. Fractal approach organizes the complex system that can be generated through the iteration and integration of the simple units and the common control rules. All theories which were used in the fractal approach (entropy, gradient, etc) can give more precise to method's calculation, but it is not necessary to be professional in these aspects to use approach. Since use worksheets and a number of multi-parametric data, it is needed to operate this information for success decision making. Assume to consider this case from the chaos theory point of view. Data analysis may be represented visually, allowing decision makers to quickly understand complex correlations and to develop the right strategies and realizations. The method of SOM is based on the Kohonen algorithm.

4. In section 4 Fractal approach for MPM was elaborated and formulated in the previous chapters. The usage of different methods was showed. FP approach integration with ERP system and into enterprise was explained.

Contribution and novelty of the research is concluded in:

- Articulating contemporary problems of MPM through the "current-world-bothered" prism of chaos and complexity. And what is important that it was done on the basis of existing technologies in manufacturing industry.
- Fractal structure of MPM, concrete approach and algorithm for its realization in MPM was justified in the particular case-study.
- Fractal MPM was successfully used with ERP system.
- Using SOM for MPM planning results estimation.

Approval of the hypotheses formulated in the beginning and other results of the research could be articulated in the following form:

1. Number of simultaneous projects represents a system with properties of self-organization. Using the proposed fractal approach a manager may direct human resources approaching maximal utilization and effort of them. Principally, the effect of self-organization causes the existence of synergy.
2. Any multi-project along with its all-level constituents (projects, activities, simple jobs) demonstrates a fractal structure. There is a strong association with an idea of fractal geometry of Mandelbrot. Moreover, it establishes a holistic viewpoint to management of project portfolio.
3. Theoretically, all the data collected during projects' implementation may be used for the post-mortem analysis. It means that even form the chaotically distributed information it may be possible to define some intrinsic patterns. This is an evident of an existence of deterministic chaos. Nonlinear interdependencies are the part of the chaotic systems. They are revealed by using SOMs based on Kohonen's algorithm. Most statistical approaches (e.g., linear and quadratic discriminate analysis, decision trees, multivariate regression, and Bayesian networks) have limitations when dealing with complex, non-linear, non-Gaussian distributed data.

Future research

As mentioned above the possibility of the FP approach with ERP systems has to be studied more deeply in a wider scope. Besides, FP approach itself may be improved. For example, it could be assumed that neither organizational structure nor size of the enterprise do create any obstacles in utilization of the proposed approach. Moreover, the results of this study and the approach itself may be used on the whole life-cycle of projects, i.e., from planning up to finishing and post-mortem analysis. Also, the perspective of studying chaotic and non-linear processes in project management looks attractive and worth-promising. Fractal features in projects have to be studied thoroughly in order to define qualitatively and quantitatively the hidden nature of the processes in MPM. CAS theory would facilitate the study of complex characteristics in MPM as well by using simulation applications.

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LIST OF PUBLICATIONS

Classification 1.2 – 6 papers

1. Polyantchikov, I., Shevtshenko, E., Kramarenko, S. *Fractal Management Approach For the Manufacturing Projects in the Collaborative Networks of SMEs.* Journal of Machine Engineering. (2010), **9**(4), 81-93.
2. Shevtshenko, E., Karaulova, T., Kramarenko, S., Wang, Y. *Manufacturing project management in the conglomerate enterprises supported by IDSS.* Journal of Achievements in Materials and Manufacturing Engineering. (2009), **33**(1), 94-102.
3. Kramarenko, S., Shevtshenko, E., Karaulova, T., Wang, Y. *Manufacturing Projects Cash-Flow Dynamics and Risk Management.* Journal of Machine Engineering. (2009), **9**, 91-102.
4. Kramarenko, S., Shevtshenko, E., Karaulova, T., Wang, Y. *Decision Analysis in Project Management Process.* J. Machine Engineering. (2008), **8**(2), 104-111.
5. Shevtshenko, E., Karaulova, T., Kramarenko, S., Y. Wang. *IDSS used as a framework for collaborative projects in conglomerate enterprises.* Journal of Achievements in Materials and Manufacturing Engineering. (2007), **22**, 89-92.
6. Shevtshenko, E., Karaulova, T., Kramarenko, S., Wang, Y. *IDSS as a tool for project management in a collaborative network of SME-S.* J. Machine Engineering. (2007), **7**(2, Manufacturing Intelligent Design and Optimization), 96-104.

Classification 3.1 – 6 papers

7. Pekšujev, D., Smirnov, A., Kramarenko, S. *Expert System for Parametric Modeling.* Proceedings of the 20th International DAAAM Symposium: Intelligent Manufacturing & Automation: Theory, Practice & Education. (2009), 1395-1396.
8. Kramarenko, S., Shevtshenko, E. *Decision support system for the Multi-project Cash-Flow management.* Proc. 20th Intern. DAAAM Symp.: Intelligent Manufacturing & Automation: Theory, Practice & Education. (2009), 1111-1112.

9. Karaulova, T., Kramarenko, S., Shevtshenko, E. *Risk Factors in Project Management Life Cycle.* Proc. 6th Intern. Conf. of DAAAM Baltic Industrial Engineering. (2008), 327-332.

10. Kramarenko, S., Karaulova, T. *Case Study of Project Management Process Improvement.* Proc. 17th Intern. DAAAM Symp. (2006), 209-210.

11. Karaulova, T., Kramarenko, S., Shevtshenko, E. *Knowledge Management for Network of Enterprises.* Proc. 17th Intern. DAAAM Symp. (2006), 197-198.

12. Kramarenko, S., Karaulova, T. *Criterions of management process estimation.* Proc. 5th Intern. Conf. DAAAM Baltic, Industrial Engineering. (2006), 207-212.

Classification 3.2 – 1 paper

13. Karaulova, T., Kramarenko, S., Shevtshenko, E. *Knowledge Discovery for Decisions Making in Network of Enterprises*. DAAAM International Scientific Book. (2007), 153-164.

My contribution to publications was incrementally growing from the earliest to the latest papers. Papers published in the period 2006-2007 papers were procured by numerical data examples for case-study from my side. My research results about methods in decision-support systems were also included. From 2008 up to present time my participation in papers bore the character of concept formulations (complexity and thermodynamics in project management, fractal theory), investigations of methods and applications in cash-flow theory, risk management. The results from papers 1, 4, 5, 9, and 11 were presented on the international conferences in Estonia, Poland, and Austria.

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Tallinn University of Technology	2003	BSc in Engineering
Mahtra High School	1998	High school education

4. Language competence/skills (fluent; average, basic skills)

Language	Level
Estonian	Average
Russian	Fluent
English	Fluent
German	Average
Japanese	Basic

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Tallinna Tehnikaülikool	2003	Tehnikateaduste bakalaureusekraad
Mahtra Gümnaasium	1998	Keskharidus

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Eesti keel	Kesktase
Vene keel	Kõrgtase
Inglise keel	Kõrgtase
Saksa keel	Kesktase
Jaapani keel	Algtase

5. Täiendusõpe

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August 2008 – Märts 2009	Central Florida Ülikool, Ameerika Ühendriigid

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2003 – 2007	OÜ BLRT Kinnisvara	Projektijuht
2008 – …	Tallinna Tehnikaülikool, Masinaehituse instituut	Erakorraline teadur-lektor

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL AND INSTRUMENTAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-bonded hardmetals. 1992.
2. **Jakub Kõo**. Determination of residual stresses in coatings & coated parts. 1994.
3. **Mart Tamre**. Tribocharacteristics of journal bearings unlocated axis. 1995.
4. **Paul Kallas**. Abrasive erosion of powder materials. 1996.
5. **Jüri Pirso**. Titanium and chromium carbide based cermets. 1996.
6. **Heinrich Reshetnyak**. Hard metals serviceability in sheet metal forming operations. 1996.
7. **Arvi Kruusing**. Magnetic microdevices and their fabrication methods. 1997.
8. **Roberto Carmona Davila**. Some contributions to the quality control in motor car industry. 1999.
9. **Harri Annuka**. Characterization and application of TiC-based iron alloys bonded cermets. 1999.
10. **Irina Hussainova**. Investigation of particle-wall collision and erosion prediction. 1999.
11. **Edi Kulderknup**. Reliability and uncertainty of quality measurement. 2000.
12. **Vitali Podgurski**. Laser ablation and thermal evaporation of thin films and structures. 2001.
13. **Igor Penkov**. Strength investigation of threaded joints under static and dynamic loading. 2001.
14. **Martin Eerme**. Structural modelling of engineering products and realisation of computer-based environment for product development. 2001.
15. **Toivo Tähemaa**. Assurance of synergy and competitive dependability at non-safety-critical mechatronics systems design. 2002.
16. **Jüri Resev**. Virtual differential as torque distribution control unit in automotive propulsion systems. 2002.
17. **Toomas Pihl**. Powder coatings for abrasive wear. 2002.
18. **Sergei Letunovitš**. Tribology of fine-grained cermets. 2003.
19. **Tatyana Karaulova**. Development of the modelling tool for the analysis of the production process and its entities for the SME. 2004.
20. **Grigori Nekrassov**. Development of an intelligent integrated environment for computer. 2004.
21. **Sergei Zimakov**. Novel wear resistant WC-based thermal sprayed coatings. 2004.
22. **Irina Preis**. Fatigue performance and mechanical reliability of cemented carbides. 2004.
23. **Medhat Hussainov**. Effect of solid particles on turbulence of gas in two-phase flows. 2005.

24. **Frid Kaljas**. Synergy-based approach to design of the interdisciplinary systems. 2005.

25. **Dmitri Neshumayev**. Experimental and numerical investigation of combined heat transfer enhancement technique in gas-heated channels. 2005.

26. **Renno Veinthal**. Characterization and modelling of erosion wear of powder composite materials and coatings. 2005.

27. **Sergei Tisler**. Deposition of solid particles from aerosol flow in laminar flat-plate boundary layer. 2006.

28. **Tauno Otto**. Models for monitoring of technological processes and production systems. 2006.

29. **Maksim Antonov**. Assessment of cermets performance in aggressive media. 2006.

30. **Tatjana Barashkova**. Research of the effect of correlation at the measurement of alternating voltage. 2006.

31. **Jaan Kers**. Recycling of composite plastics. 2006.

32. **Raivo Sell**. Model based mechatronic systems modeling methodology in conceptual design stage. 2007.

33. **Hans Rämmal**. Experimental methods for sound propagation studies in automotive duct systems. 2007.

34. **Meelis Pohlak**. Rapid prototyping of sheet metal components with incremental sheet forming technology. 2007.

35. **Priidu Peetsalu**. Microstructural aspects of thermal sprayed WC-Co coatings and Ni-Cr coated steels. 2007.

36. **Lauri Kollo**. Sinter/HIP technology of TiC-based cermets. 2007.

37. **Andrei Dedov**. Assessment of metal condition and remaining life of in-service power plant components operating at high temperature. 2007.

38. **Fjodor Sergejev**. Investigation of the fatigue mechanics aspects of PM hardmetals and cermets. 2007.

39. **Eduard Ševtšenko**. Intelligent decision support system for the network of collaborative SME-s. 2007.

40. **Rünno Lumiste**. Networks and innovation in machinery and electronics industry and enterprises (Estonian case studies). 2008.

41. **Kristo Karjust**. Integrated product development and production technology of large composite plastic products. 2008.

42. **Mart Saarna**. Fatigue characteristics of PM steels. 2008.

43. **Eduard Kimmari**. Exothermically synthesized B_4C-Al composites for dry sliding. 2008.

44. **Indrek Abiline**. Calibration methods of coating thickness gauges. 2008.

45. **Tiit Hindreus**. Synergy-based approach to quality assurance. 2009.

46. **Karl Raba**. Uncertainty focused product improvement models. 2009.

47. **Riho Tarbe**. Abrasive impact wear: tester, wear and grindability studies. 2009.

48. **Kristjan Juhani**. Reactive sintered chromium and titanium carbide- based cermets. 2009.

49. **Nadežda Dementjeva**. Energy planning model analysis and their adaptability for Estonian energy sector. 2009.

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55. **Tõnu Roosaar**. Wear performance of WC- and TiC-based ceramic-metallic composites. 2010.

56. **Alina Sivitski**. Sliding wear of PVD hard coatings: fatigue and measurement aspects. 2010.