Engineering Design Performance Management – from Alchemy to Science through ISTa

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Abstract: The drive for performance is omnipresent in modern society. We believe this to be true, although we only have a vague idea of what "performance" really means. The demand for management is omnipresent in modern society. We accept this to be true, although management theory is a science barely out of its infancy (Who wishes to be supervised by an infant?). Performance management is considered to be the need for the hour in modern society. We are told this is true, although we feel that we are trying to cope with something that we have very little comprehension of. Engineering is the omnipresent backbone of modern society. We experience this to be true, although we acknowledge that design is least as much an art as it is a science, a world where uncertainty rules. The impact of Information Society Technology (IST) is omnipresent in modern society. We understand this to be true; although we know that there is no point in automating something we don't understand. Somewhat ironically, one could conclude that Engineering Design Performance Management (EDPM) is about the challenge to handle the uncertain and appraise the unknown. Not to forget about IST embarked on a mission to automate everything it possibly could to pretend that there are ready answers. This is like alchemy, but for performance. Alchemy hovered between worlds. So does contemporary performance management hovering between fiction and reality. Alchemists proposed to use the philosopher's stone (materia prima), a mysterious, unknown substance that they believed to have the power to transmute base metals into gold. So does contemporary performance management by hailing IST as its "Magnus Opus". Without a doubt, it is high time to rebuild a firm foundation of performance management. We need a consistent framework addressing the relevant aspects of performance management from the abstract level to the concrete level. Only than IST will be able to unfold its full potential, and deliver on its promises. The strategic potential of IST does not lie in empty automation that enforces unrealistic and oppressive processes. It lies in enabling better decision making in a highly complex environment of change, uncertainty, risk, and urgency.

1. Introduction

There is a common understanding that performance management is of paramount importance for success in any field. Be it business, politics or any other humans' activity – it's a must-have. The size of the performance management market ranges from several billion dollars in annual revenue to much more depending on which products and services are included. In contrast to this, performance management reality seems to be still far from fulfilling its original promise, to pro-actively and efficiently support the management of performance. Despite it, Cadence Design Systems has proved that performance management can be of extraordinary value as long as some fundamental guidelines are considered. This is true even if the results have to be interpreted and justified by referring to sometimes intuitive understanding of business factors. The main guidelines are: (a) always seek to be very targeted rather than general; (b) move beyond the mere representation and reflection of data towards providing evaluation and prediction capabilities; (c) comprehensive modeling is the key to the design of performance management systems. To our opinion providing a comprehensive theoretical framework for performance management in these settings may bring unquestionable competitive advantage. The pity is that such a “silver bullet” is still missing today. Even worse, performance management is a field where it is not unusual that fact and fable are blurred beyond distinction.

The paper is focused on the case of engineering design performance management at the project level. Presented theoretical developments will be backed up by the software tool implementation and evaluation results, which address one of the key performance metrics – the productivity. Productivity is assessed through simulating and analyzing the dynamic character of an engineering design process in integrated circuit (IC) design with appropriate level of granularity. The primary focus of this paper is to create the awareness for a strategic opportunity to significantly mature performance management in engineering design. The reminder of the paper is divided into four sections. In section 2 we sketch the elements and contour a rigorous framework for performance management inspired by an “axiomatic system” of economics. Section 3 deals with the relevant performance management background concerning semiconductor industry and IC design. A typical engineering design performance management system will be described. Section 4 focuses on modeling IC design performance. Multi-agent approach is being used to model real, complex design systems and their environments. This is where the strategic opportunity for Information System Technologies through exploiting agents (ISTa) comes in. The final section of the paper summarizes the intermediate results of our research and offers some concluding remarks. Furthermore, it proposes follow-up activities in the context of a larger integrated approach focused on the development of an engineering design performance management system.

2. A Rigorous Framework for Performance Management

This section places special emphasis on the definition of “performance”. It also covers the essence of some main concepts around “performance”.

The framework for performance managements is rigorous in the sense that we rely on self-evident axioms of various schools of economics. These axioms are then be used, along with some rules of inference, to derive several corollaries of interest. That is, the rigor comes from logical formalism. The framework supports modularity and reusability of results in the sense that one can always use results established previously and in different context without having to prove those results from scratch.

2.1 Performance

The term "performance" is heavily used nowadays. For example, Google yields approximately 393.000.000 hits[1] for "performance". Assuming a positive correlation between the number of hits on the World Wide Web and the importance of a term in contemporary society, "performance" is definitely among the top terms used. To compare the search for an undeniably important term like "human" results in 418.000.000 hits[2], which is only marginally ahead of "performance". It seems that "performance" is considered to be a magical formula for human success.

"Performance" lurks all around us. One can't escape from it; there is nowhere to flee. It's everywhere and in everything one does - cradle-to-grave. There are seemingly countless word-combinations with the word "performance" in it. To give a glimpse of this, here are a few examples of what is available: high-performance baby wipes (from cradle!), kindergarten performance, performance school, performance university, performance institute, performance bike, performance agreements, performance poetry, performance period, network performance, environmental performance, computer performance, performance poetry, performance objectives, performance agreements, performance appraisal, performance art, performance grave (to grave!) and many more. So, why becomes "performance" that popular? And, being such an ultra-popular term these days, doesn't "performance" become almost completely meaningless? If anything, what is it that people are trying to say when they speak of "performance"?

Perhaps the definition of "performance" will lead to some answers. This, however, turns out to be a somewhat naive hope. More then ten years ago, Meyer and Gupta [MG94] pointed out that there is "*massive disagreement as to what performance is*". A recent review of existing definitions of "performance" conducted by Ivasiva [Iv05] confirms their finding and highlights two main points: (1) there are many definitions of "performance" and new ones are continuously added; and (2) the "performance" definitions proffered by the performance proponents – whether from academia or industry – suffer from a persistent inability to provide unique, complete , unambiguous, and, acceptable definitions. Of all these attributes, perhaps the last one is the most important one. A definition is acceptable when a number of people agree on it or commit to it. However, the consensus upon the definition of "performance" is still missing. On the contrary, the trend towards opting for 'seductively vague' definitions continues unbroken to this day. A few recent examples – chosen from the vast supply of "performance" definitions – are:

- Baldvinsdottir et al [Ba03]: "*Performance is defined as carrying out tasks in a situation that allows optimal outcome.*" The issue that immediately arises with this definition is the exact meaning of "a situation that allows optimal outcome". We don't

[1] As of April 7, 2005.
[2] As of April 7, 2005.

know. Seemingly, the authors have chosen to employ a tautological conception of optimality. Under such a conception everything is adjusted to everything else given all relevant constraints. Saying that a situation allows for optimal outcome means that it allows exactly what it allows given all situational constraints.

- Faulk II [Fa02]: "*Performance is defined as the accomplishment of job duties as required by the organization.*" This is a much too-narrow definition. For example, what about any accomplishments for the organization that are above and beyond the required job duties? According to the above definition those accomplishments would not be attributed to "performance". However intuitively we know that this can't be the case. In fact, what is done above and beyond the job duties generally accepted as a major contribution to "performance".
- Hall [Ha03]: "*Performance is defined as the combination of competence in job skills and high levels of productivity.*" This attempt of a definition combines two disparate concepts – competence, which is a human ability and productivity, which is a neo-classical economic metric - into a single "mechanism" called "performance". What is the author trying to define here?
- Melchert and Winter [MW04]: "*Performance is defined as valued contribution to reach the goals of an organization.*" This is just another approach of defining "performance" that is seemingly both limited and inadequate. Who valuates a contribution? What happens if a contribution is not valued? From the above definition it follows that any contribution that is not considered to be a valued contribution – by whomever – is not "performance". This will be true, regardless of the significance a contribution has to reach the goals of the organization. Too bad if it is just not valued.
- Andersen and Fagerhaus [AF02]: One of the most remarkable definitions of "performance" is the null-definition by Andersen and Fagerhaus. According to them it is simply not reasonable to strive for the "performance" definition: "*We believe it is sufficient to have reached a point where performance has replaced productivity and is generally accepted to cover a wide range of aspects of an organization – from the old productivity to the ability to innovate, to attract the best employees, to maintain an environmental sound outfit, or to conduct business in ethical manner.*" "Performance" has replaced productivity? But were we not educated that high-levels of productivity determine "performance" [Ha03]? There are alchemists out there.

O'Donnell and Duffy [OD02] suggest "*In summary, the research in performance has been hindered by a lack of clarity on its meaning.*" We agree wholeheartedly with this statement. But there is always hope:

- Harkema [Ha02]: "*Performance is defined as a number or series of activities directed toward an outcome.*" This definition comes closest to encompassing all of the wide and varied sorts of "performance". Yet it is not perfect, as it contains the ambiguous phrase "*number or series of*". Furthermore, "*directed*" seem to indicate some "outside" control or intention. This is an unnecessary restriction, which results in a too-narrow definition of "performance".

In a situation like this, it is advisable to go back to the roots and use the etymology of "performance". In addition it is sensible to pin down the standard dictionary definitions. This information can then be used as a framing device for a comprehensive "performance" definition. According to the Chambers Dictionary of Etymology [Ba88], "performance" was formed around 1500 AD from the English "*perform*" and the suffix "*-ance*". "*Perform*" is derived from the Old French "*par*" (completely) + "*fornir*" (to provide, furnish). The suffix "*-ance*" labels "performance" as a noun of action. As for the standard dictionary definitions we have: (1) the Oxford-English-Dictionary-Online[3] defines "performance" as "*the action of performing*" or "*something performed*", (2) the Miriam-Webster-Online Dictionary[4] refers to "performance" as "*the execution of an action*", or "*something accomplished*", and (3) the American Heritage Dictionary[5] says "*the act of performing*", or "*the state of being performed*."

The etymology and the standard dictionary definitions of "performance" suggest that "performance" is derived from the root concept (or summum-genus) for intentional action. Therefore, we arrive at the following definition of "performance":

Definition 2.1.1 (Performance): *Performance is intentional action.*

This definition of "performance" is valid under all circumstances and for all context-specific situations. However, all other "performance"-related concepts have to be defined as specialization of this root-concept. This is of central importance as the "performance" of something is always context based. It should further be noted that not all actions are intentional. The notion of intentional action can be contrasted with accidental as well as with unintentional action.

2.2 Performance Management

Performance is intentional action. It is self-evident that any means, which supports the realization of intentions, is relevant in the context of performance. Management is said to be such a means. Therefore, performance should be managed. In a nutshell, this is what performance management is all about.

From the point of general concept, management has two basic dimensions. One, "linear management", centers on striving to continually improve practices and processes. Along this dimension managers plan, budget, organize, staff, direct, supervise, control, etc. Linear management is solely applicable to situations of relative stability. For historical reasons (industrial society), most of the contemporary management knowledge is about linear management. An example for a linear management technique is Total Quality Management (TQM). The other dimension, "non-linear management", centers on coping with change. Along this dimension managers respond to and anticipate change by aligning, motivating, and inspiring humans. Non-linear management has to be adaptive, whereas linear management is mainly plan-driven ("plan-pushed"). Non-linear management has to be "environmentally-pulled", that is, managers are directed more by responses to their environment than to a central command authority. Linear management prescribes what to do. Non-linear management enables how to determine what to do. Unmistakably, non-linear management is considerably more difficult than linear

[3] http://www.oed.com/
[4] http://www.m-w.com/
[5] http://www.bartleby.com/61/

management. Examples for non-linear management techniques can be found under the topic of “Agility” (the ability to perceive changes and establish appropriate techniques to cope with them).

Ubbesen[6] provides the following metaphor to describe the significant difference between linear and non-linear management: “*We could imagine that we have a line, and then we put a cross at one end and write the word problem. In accordance with our ordinary way of thinking, the word solution should consequently be placed at the other end. What do we do if the good solution is somewhere outside the line? As a matter of fact, creative consciousness is not bound to the line, it moves within a larger field of solution methods.*"

In today’s business reality both management dimensions are present and necessary. However, the ratio between them is what makes the difference. Change was always with us, it always will be. We have to cope with change. We always have been and we always will be. But the pace and breadth of change have exceeded the response methods that once worked. That is linear management tends to “ignore” or “discourage” change until serious problems vent in a “volcanic eruption”. With change more rampant today than ever, companies are required to utilize increasingly non-linear management techniques. However, the reality looks quite different. Most companies are “over”-managed in the linear sense and “under”-led in the non-linear sense. As for IST it is important to note, that the it’s benefits can’t be realized until non-linear management becomes as well understood as linear-management that has been taught to every manager since the maturation of industrial organization practice in the early part of the last century.

Given the popularity of “performance” in modern society it is not surprising that performance management is very much in vogue amongst in virtually every area of human activity. Journalists, management consultants, and performance management solution providers alike seem to be overly excited by the topic. But performance management as a discipline of management theory is still in an embryonic state. In fact, “*performance management as an identifiable subject for academic study and research arguably began in the mid-1990*” [TB04]. We find myriads of papers on performance management, we find a significant and fast growing performance management market, but we don’t find a mature, or even a suitable framework of the non-linear management of performance. Despite the significant research efforts, the result is not the expected one. Probably the main reason for this unsatisfactory situation is the highly interdisciplinary nature of performance management research, involving many fields of varying states of maturity and methodological practice. Disciplines that play a vital role in performance management research are for example: economics, engineering science, management theory, cultural anthropology, psychology, education, artificial intelligence, philosophy, and so on. Additionally, there are professionals missing that are particularly skilled at integrating multiple research disciplines into a single perspective. The enforcement of IST in such an immature environment is contra-productive. Automating a mess, leads to an automated mess. High-tech cannot bring order where there is disorder or cannot "improve" people behavior. For example, experiences in Western (and

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[6] http://www.aaa.dk/aaa/ledelse-og_organisationsudvikling.eng.pdf

increasingly Eastern) countries have shown again and again, that the introduction of IST into a company with organizational problems does not solve the problems and does not increase performance. On the contrary, it tends to make the situation worse.

2.3 Performance Management Market

The performance management market is basically an IST market. However, the lack of clarity around the definitions of performance and performance management means that almost anybody can claim to provide solutions in this space. Consequently, each vendor seems to have a self-serving flavor of performance management as indicated by the bewildering acronyms that come with "performance management solutions". There are APM (Asset Performance Management), Business Intelligence (BI), BPM (Business Performance Management), CPM (Corporate Performance Management), EPM (Enterprise Performance Management), FPM (Financial Performance Management), HPM (Human Performance Management), OPM (Operational Performance Management), PPM (Project Performance Management), SEM (Strategic Enterprise Management), WPM (Workforce Performance Management) and so on. Some of these appear to be different acronyms for the same thing (e.g., CPM and EPM), but others are fundamentally different concepts. For example, FPM targets budgeting and planning, while WPM refers to compensation and motivation planning for employees. In any case, it is obvious that there are alchemists out there.

In this world of performance management hype, even a simple project management tool can make it to the status of a PPM solution. So, is it all hype? Absolutely not. There are quite some real solutions to real performance management problems. However, most of these solutions are restricted to deal only with deterministic, sequential processes. However, they represent only a subset of the performance management problem space. For example, all types of reporting systems that are targeted to eliminate hand-tinkered, labor intensive processes information processes used to produce reports and consume their contents fall into this category. As these processes are usually expensive, slow, and error-prone, an IST solution is may be more than adequate.

Whatever information demands investors, regulators, and managers have, clearly there is a need for the corporate reporting supply chain to eliminate the hand-tinkered, labor-intensive processes currently used to produce reports and consume their contents. It's expensive, it's slow, and it's error-prone. Consequently, there is a market for performance management solutions. Despite their differences, almost all performance management solutions have three main deficiencies in common: (1) they only reflect and represent data (as opposed to evaluation and prediction capabilities), (2) they focus creating metrics based on available date (as opposed to let a sound metric system drive the data collection), and, (3) they enforce unrealistic and oppressive processes (as opposed to reflect the real-world dynamics). Technology for technology's sake is a sure path to failure. Technology for sheer business' sake is even worse. Automating a mess helps only to get the wrong answer faster. We have heard this many times before. Though we have heard this many times, most of us seem to be unable to comprehend it.

Copland[7] indicates a first step out of this mess: "*The first task facing the … industry is that it needs to tidy up its terminology and clearly express what it means by performance management and the technical solutions necessary to support it*."

However, the development of ontologies for performance, performance management, performance measurement, etc. is only the beginning. Much more research has to be done to provide a solid basis for the development of performance management solutions. Here, special attention has to be paid to the modeling of performance. Obviously this is the weakest point in today's performance management solutions. Due to the heterogeneity and complexity of the problem this requires a focus on manageable pieces as opposed to all-in-one solutions. Consequently, the industry needs to refrain from using oversimplified approaches and promising total solutions. Sure, it will be a laborious way, but if we can paint an idea of the success that can be reached by it we should be ready to take the pains.

To summarize the main lessons of the current commercial performance management solutions: (1) always seek to be very targeted rather than general (small is the next big thing in performance management solutions), (2) move beyond the mere representation and reflection of data towards providing evaluation and prediction capabilities, and, (3) comprehensive modeling is key to build successful performance management solutions.

2.4 An Axiomatic System of Economics

After having analyzed performance and related concepts, we can start building a rigorous framework for performance management. Kay [Ka96] argues that it is economics that can provide the science that management presently lacks, that economics is the natural backbone of business management. In fact, economics provides an integrative conceptual framework for much of management science. The language of economics is therefore the first language in which we will articulate a framework for performance management.

Economics is a social science. In social sciences, the subject of inquiry and analysis is the behavior of a human or a group of humans. So should it be in performance management, which professes to be founded upon and be the part of the social sciences. But when it comes to technology, all too often this is forgotten. Despite all performance management rhetoric human beings are modeled at best as statistical entities, at worst as mere phantoms of empty abstraction. Whether we like it or not, this mechanistic view of the world drives much of what we experience in industrial performance management practices today.

It should be noted, that economics could – with the notion on "could" – be viewed as pluralistic discipline. As such it should not support the "dangerous delusion" of a universal economic theory applicable to human behavior in all societies, at all points in time. In fact, there are many different and competing schools of economic thought and methodology. Unfortunately, barriers between them are substantial. For the sake of

[7] http://www.fsn.co.uk/feature_articles/testing_time_ahead_for_performance_management_vendors.htm

developing the performance management framework we will ignore any boundaries between potentially entrenched schools of economics.

We defined performance as intentional action. It is therefore only consequent to look for an economic school, which puts action at its heart. This leads us to the so-called Austrian School of economics, a controversial school standing to some extent outside of the mainstream of economics. The school of Austrian economics is well known for its "realistic" approach to the study of human action. Ludwig von Mises, one of the fathers of Austrian School, states in his landmark work on Human Action [Mi63]: "*Human action is purposive behavior. Or we may say: Action is will put into operation and transformed into an agency, is aiming at ends and goals, is the ego's meaningful response to stimuli and to the conditions of its environment, is a person's conscious adjustment to the state of the universe that determines life*." Perhaps as amazing as von Mises' economic thinking was the fact that the economic community largely ignored his work until about 20 years ago. This is symptomatic for the general lack of mutually beneficial exchange of ideas between the various economic schools.

Praxeology[8], a methodology of the Austrian School, rests on the axiom of action (see Axiom 2.4.1), the proposition that humans act, that they display intentional behavior[9]. The axiom, qualifies as a priori synthetic knowledge because (1) the axiom cannot be denied since the denial would have to be categorized as an action, and (2) the axiom is not derived from observation — there are only bodily movements to be observed but no such thing as actions — but stems instead from reflective understanding [R076]. The most distinctive feature of praxeology is its intrinsic *a priori* approach. Corollary axioms must be logically deduced from antecedent axioms, so that – provided the initial axiom is true – "*the conclusions reached are just as valid as any result in Euclidian geometry*"[10]. Since "*praxeology begins with a true axiom, A, all the propositions that can be deduced from this axiom must be true. For if A implies B, and A is true, then B must also be true.*" [Ro76].

Axiom 2.4.1 (Axiom of Action): *Man acts (intentionally).*

In anticipation of Chapter 4, where we shall discuss the modeling of a Dynamic Engineering Design Process (DEDP), it should be noted that this axiom evidently points out that a software agent is a good metaphor to model humans. Indeed, agents also act – i.e. they do it intentionally and, moreover, pro-actively pursuing their goals.

The second major axiom is the axiom of scarcity (Axiom 2.4.2). Ironically, neo-classical economics, which considers itself as superior to Austrian economics, begins with the premise that resources are scarce.

Axiom 2.4.2 (Axiom of Scarcity): *Scarceness is rewarded.*

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[8] The term praxeology was first applied by Ludwig van Mises [Mi63].
[9] The relationship between the axiom of action (Axiom 2.5.1) and performance (Definition 2.1.1) is obvious.
[10] http://www.mises.org/story/1304

The axiom of scarcity is one of the fundamental axioms in economics, yet it is often not well understood as demonstrated by the famous diamond-water paradox (Paradox 2.5.1) and Drucker's statement about the end of economic theory (Misconception 2.5.1).

Paradox 2.4.1 (Diamond-Water Paradox): *Diamonds are inessential to life, yet they command a high price. Water is essential to life, yet it commands a low price.*

This paradox depicts the difference between a price and a utility. One would think that the more essential, the higher the price. But this is not the case. The importance of water is reflected in its total utility, which is much more than the one of diamonds. But price is proportional not to total utility, but to marginal utility. And because water is so much more abundant than diamonds the marginal utility of water is much lower than the more scarce diamonds.

Peter F. Drucker, is the world's most widely read and influential thinker on business and management. He is considered to be "*the father of modern management*"[11] and "*the man who invented corporate America.*"[11] So, what does he have to say?

Misconception 2.4.1 (Drucker's End of Economic Theory)[12]: "*... there is no doubt that we are at the end of economic theory as we know it for three reasons. One is that information and knowledge don't fall under the law of scarcity and under the law of diminishing returns. That's a very important reason. When I sell you my book, you have it, and I don't have it anymore. When I give you information, I still have it. In fact, I have more, because now you have it, and we can work together. For that, we have no economics.*"

Given Drucker's immense influence on the management community we should be scared about the performance management future, not to mention economics. But Drucker is not alone. Saul Bellow, the 1976 Nobel Laurate of Literature, philosophizes in the Wall Street Journal, January 1, 2000[13]: "*So there does seem to be some possibility that mankind's long war with scarcity may be tapering off.*" Thomas Petzinger Jr. quotes in an article with the suggestive headline "So Long Supply and Demand" [Pe00] several witnesses for the end of economics in general and the axiom of scarcity in particular. For example, Mark McElroy, a principal in International Business Machines Corp.'s Global Knowledge Management Practice said: "*Conventional economics is dead. Deal with it!*" Of course, it is easy to recognize that all of the above claims are complete nonsense. However, the problem is that these claims conform to the prevailing fashion of business management "theology". The problem is that notable authorities, newspapers, books etc evangelize them. The problem is that they seem to be perfectly reasonable to a broad business community. The problem is that these claims develop real enforcement power: Anyone who doesn't believe in them just doesn't get it. There are alchemists out there.

In a may be more comprehensible way, the axiom of scarcity states that people want more of what they can't have. Scarcity is and always will be with us – it is simply part of

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[11] http://www.pfdf.org/leaderbooks/drucker/bio.html

[12] http://www.contextmag.com/setFrameRedirect.asp?src=/archives/199903/Feature1ECONOMICSGOESTILT.asp

[13] http://www.greenstar.org/Jan00-Update/

the human spirit. Beware anyone who says otherwise! The axiom of scarcity is the ultimate reason why man needs to manage performance. Furthermore, the axiom qualifies productivity as the single most important performance metric. It is important to note that resource in the economic context is always a consumable or consumed resource. Therefore knowledge is not a resource. However, man, who as the carrier of the knowledge is. With every hour worked man gets older. That is man gets consumed.

There are two more axioms of interest for our framework. First, the axiom of impatience (Axiom 2.4.3). This axiom introduces time as a variable into the performance management picture. This is important for situations where productivity and time need to be traded off against each other. It is therefore essential to understand and manage performance. The axiom of competition (Axiom 2.4.4) states that man must compete. It is a direct corollary of the axiom of scarcity (Axiom 2.4.2) and the axiom of impatience (Axiom 2.4.3). It follows that performance is an interdependent phenomenon.

Axiom 2.4.3 (Axiom of Impatience): *Man prefers consumption sooner rather than later*.

Axiom 2.4.4 (Axiom of Competition): *Man must compete*.

The final corollary in this contour of a performance management framework is:

Corollary 2.4.1: *Performance matters*.

The framework described in this chapter is obviously incomplete. However, the important thing is the methodology applied to build the foundation of performance management framework. It should be clear from the few examples provided above that many management gurus find it unnecessary to apply even the few basic axioms presented, thus depriving performance management the rigid foundation that is clearly needed. Any IST solution is doomed to fail by applying nebulous concepts as the basis for technology development.

3. Semiconductor Industry and IC Design

Let us now outline relevant performance management background concerning semiconductor industry and IC design. In this section a typical engineering design performance management system will be described pointing out its typical features and system laws.

3.1 The Semiconductor World

The semiconductor business dates from 1947, when the point contact transistor was invented [Ba56]. Today, life without semiconductors' Integrated Circuits (IC) cannot be imagined and the health of the global economy and that of the approximately $200 billion revenue semiconductor industry are closely intertwined. The semiconductor industry is considered to be the most productive industry of all times. Gordon Moore asserts: "*Since I've been in the business the cost of the transistor has gone down some ten million fold. There is no industry I can identify in the history of mankind where a similar kind of an improvement in cost has been made, particularly over a relatively short period of time*."[14] The complexity of today's multimillion- and now billion-transistor chips is hardly surpassed.

The dynamics of the semiconductor industry can be explained based using the concept of system law. A system law is a rule (or a set of rules), which generalizes the behavior of some observed phenomenon within a concrete system and its given spatiotemporal context. A system law tells an agent of the system what behavior is expected. Thus a system's law can enforce change or represent a barrier to change. It can be used to predict certain aspects of the system behavior, which are based on the force, or influence it exerts on the internal environment of the system. In contrast to a natural law, a system law is neither universal nor does it need to be true, correct, etc. In fact, it doesn't matter where it is made of or where it comes from. It is, for whatever reasons, in force. However, where it is impossible to change laws of nature, a system law may be very well changed by human powers. It needs to be emphasized that system laws are not laid down once and for all, and especially not to dictate what we can or cannot think. They are tools for helping us to think; and most of all, to be transcended if necessary.

The two most important system laws of the semiconductor industry are Moore's Law and Noyce's Minimum Information Principle. Gordon Moore and Robert Noyce founded Intel in 1968. Moore's Law states that every 18 months, processing power doubles while cost holds constant. According to Noyce's Minimum Information Principle, a researcher guesses what the answer to a problem is and goes as far as he can in a heuristic way. If that doesn't solve the problem, he backs up and learns enough to try something else. Thus, rather than mounting complex and expensive research efforts aimed at a deep understanding of all the facets of an effect our scientist-engineer try to get by with as little information as possible to make something that work. Developing a deliverable product is the only goal. The implications for semiconductor industry performance in general and IC design in particular are obvious. Moore's Law imposes a clock rate on the technological progress to be achieved. Noyce's Minimum Information Principle enforces the concept of how to act.

3.2 The World As Experienced by Mr. Deed

In this chapter we will give a few revealing glimpses into current performance management practices in engineering design of the semiconductor industry. Much has been said and written about the benefits of performance management for executives , shareholders and other stakeholders alike. Here, on the contrary, we shall use the viewpoint of a performance managed 'victim'. We will introduce a fictitious character, which we shall call Mr. Deed. Mr. Deed is a design engineer. As an engineer he wants to change the world by deeds. However, his name could be interpreted as the acronym for

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[14] http://www.intel.com/pressroom/archive/speeches/euv91197.htm

Design Engineer Experiencing Distress, which somehow indicates the price he has to pay to be a design engineer.

Here are some of the highlights of Mr. Deed's encounters with performance management in general and IST in particular:

- Encounter 1: Find out - what is the society of the day?
  Start the clock two million years ago, when our genus first appeared. From then to now societies developed from hunting and gathering societies, to horticultural and pastoral societies, to agrarian societies, and finally to industrial societies. Two million years for four types of societies. But nowadays the society Mr. Deed lives in seems to change daily. There are the Communication Society, the Digital Economy, the Dream Society, the Experience Economy, the Era of Glocalization (Globalization & Localization), the Information Society, the Knowledge Society, the Learning Society, the Network Society, the Post-industrial Society, the Service Society, the Ubiquitous Network Society, and more.
- Encounter 2: Use the Automated Travel Expense System.
- Encounter 3: Use the Automated Purchase System.
- Encounter 4: Use the Automated Human Resource Development System.
- Encounter 5: Use the Automated Project Management System.
- Encounter 6: Use the Critical Incidents Reporting System.
- Encounter 7: Use the Automated Time Tracking System.
- Encounter 8: Use the Customer Relationship Management System.
- Encounter 9: …

With all this grandiose performance management IST, what are the realities of the industry? The reality looks much less grandiose. 85% of all IC design projects are running over budget and time. The average delay is about 53%. 48% of all IC designs require a redesign. 37% of all redesigns are caused by design failures. This is pretty much a disaster for the most productive industry of all times.

The point is that all IST Mr. Deed encounters is based on linear management paradigms. However, most engineering design in the semiconductor industry is a somewhat chaotic activity. To overcome this situation Mr. Deed would need an IST that is based on non-linear management paradigms. Unfortunately his management ignores this request. His management believes in discipline, the usual inspiration for methodologies, the "secret weapon" to magically smooth-out any non-linearity. Now, engineering methodologies have been around for a long time. They have not been noticeable for being terribly successful. They are even less noted for being popular. The most frequent criticism of these methodologies is that they are bureaucratic. There are so many things to do to follow the methodology that the whole pace of development slows down. This of course is in conflict with the pace of business. And it is in conflict with Moore's Law. The enforcement power of both is unquestioned in the semiconductor world. That is "the methodology" will be dropped and Noyce's Minimum Information Principle comes to power again. This in turn may very well result in some chaos. Of course, working in chaos does not come for free. Distress is the price Mr. Deed has to be prepared to pay in the pursuit of being a design engineer. What would be required to mitigate or overcome this problem? And what is a potential contribution of IST? The key lies in the adequate modelling of “designing”.

4. Alchemy and Contemporary Performance Management

Let’s now focus on how we may forge the model of IC design performance based on the preliminary theoretical findings and real industrial experience outlined above. We shall present the framework for modeling engineering design processes. The purpose for such modeling is to obtain the means to access the productivity of such performance. As hinted above agent paradigm provides plenty of features, which are very relevant to our problem domain. This is why agents are used to model real, complex design systems and their environments. Romantically speaking we consider an agent a Philosopher's Stone of today’s engineering design performance modeling domain. The paradigm has expressive power enough for transforming “base metals” (like enterprise knowledge) into “silver” or “gold” (like optimally performed design processes). However, lots of work is still to be done before the Philosopher's Stone will become a Silver Bullet – i.e. will become a methodology, which will enhance the performance by the order of the magnitude. This task is a real challenge because the processes of engineering design “… are frequently chaotic and non-linear, and have not been well served by project management or workflow tools” (cf. [NSB01]). The primary reason is that the ability to design is one of the signatures of human intelligence, which can hardly be framed by the rigid and static bounds of pre-defined business processes. The only way to make engineering design effective and efficient is to make its processes flexible – i.e. self-adjusting, self-configuring, and self-optimizing at run time. By doing so we may enhance the degree of coherence between the interrelated activities in such processes and make them better coordinated and therefore better performed. The first results of our PSI project[15] on this way are presented in the reminder of the section.

Improving the performance of Dynamic Engineering Design Processes (DEDPs) in terms of engineering design productivity is the focus of PSI. The project aims to implement a software tool, which will provide for the assessment of the accomplished DEDPs and the prediction of the characteristics of the planned DEDPs through their simulations. This simulation tool is thought and implemented as a multi-agent system which models designers’ teams working on projects by dynamically formed teams of software agents, DEDPs performed by these teams – by tasks, and the results of these processes – by design artifacts. The knowledge on the performed processes is formalized in terms of DEDP family of ontologies and stored to PSI test bed. Through that we obtain the incremental collection of actors’ experience, which is further on used to make simulation results more reliable. In fact the implemented demo prototype of the simulator works in the following two modes: playback and “freestyle” simulation. Playback mode stands for the simulation of a DEDP, which has been already accomplished, fully recorded to the test bed. In this mode all the details of the process execution are available and the simulation simply reconstructs the process flow. “Freestyle” mode is more interesting. In this mode we may predict the possible

[15] PSI – Productivity Simulation Initiative – research project of Cadence Design Systems GmbH

development of the process through allowing agents to act according to their knowledge about the tasks, their beliefs about the peers, and the goals they receive through the initial task specification. "Freestyle" simulation is the main mode, which is used in our prediction-correction methodology for DEDP planning. Of course, the knowledge of the DEDPs collected on the test bed is used as the kind of the training set allowing our agents to make more grounded assessments in different types of negotiations.

4.1 DEDP Model

A DEDP is the process of aiming a weakly defined engineering design workflow to achieve its goal in an optimal way in terms of result quality and gained productivity. In PSI we consider that workflow formation occurs at the run time. It is therefore clear that the following entities are involved in the process: actors, who form design teams and collaboratively do the work in the flow; activities which are actually the atomic parts of a workflow defined by the technology used in the house; tasks which are subjective actors' representations of activities' compositions and choreography[16]; and design artifacts which are in fact the results of engineering design activities. Hence in our understanding, only the so-called "atomic" engineering design activities are defined by the design technology and are well known before a DEDP starts. Other elements may only "become apparent" at run time because:

- The treatment of an activity as atomic or composite is different by the actors having different capabilities. An activity, which is perceived as atomic by one actor, may be recognized as the composite one (i.e., a task) by another actor. This DEDP feature implies the necessity to cope with distributed planning.
- The composition [Er04] of the atomic activities is defined only subjectively and partially. Composite activities, which are denoted as tasks in our model, may be composed of the subjectively atomic activities in different ways by different actors who have different knowledge models. One of the implications is that the sequence of atomic activities in a task may be understood differently in the partial local plans of different actors. These complications imply the necessity to cope with distributed scheduling.
- The number of activity loops is not defined in advance. It depends on the quality checks at intermediate steps. Changing the number of activity loops may cause the changes in its duration. In turn, it may cause the delays of the dependent tasks and activities with associated penalties for, e.g., deadline violation. This group of effects implies the need for run-time re-planning and re-scheduling.
- Moreover, the duration of activity execution is not defined in advance. Different actors possess different capacities to be spent for the activity at a certain time. They may perform the same activity with different productivity. An activity may remain idle while waiting until the pre-conditions have appeared. The idle state duration can't be computed in advance because the preconditions may be formed by the other activities executed by other actors. Run-time re-scheduling may be again necessary to resolve the influence of these effects.

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[16] Choreography in the mentioned context is understood similarly to Web Services choreography and means the way of arranging material input – output communication among the dependent activities.

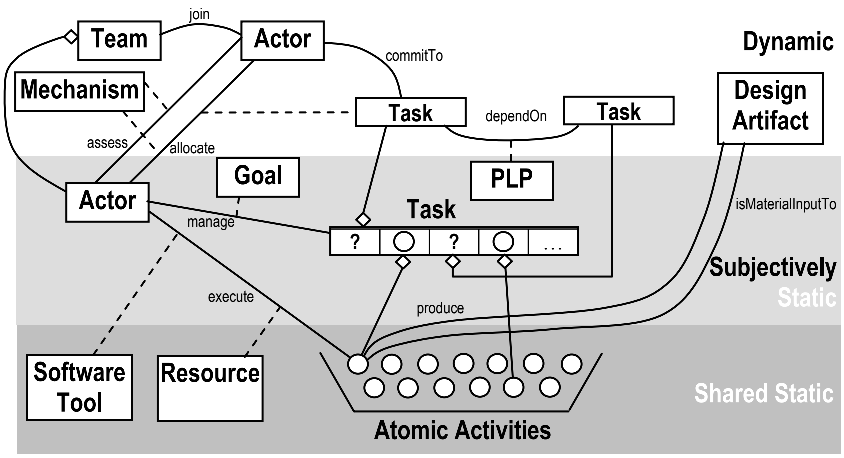

Fig. 1. Static and dynamic components of DEDP modeling framework.

- The actors are not assigned in advance to perform certain activities. The Task Manager chooses an actor when s/he decides to assign or to out-source the activity. In PSI framework contracting negotiations are the means to optimally choose the actor to perform the task. DEDP model should therefore incorporate the actor model and the means to arrange their collaboration through peers' assessment and negotiations (self model, the model of a peer, negotiation protocols and strategies, communication model).

Mentioned factors provide certain degrees of freedom[17] in DEDP planning, scheduling, and execution. In PSI a DEDP is not rigidly planned before it starts. The decisions on how to continue its execution are taken each time it reaches a certain state in the state space. These decisions are taken by the design team members who manage the tasks, which continue the process. It is important that, according to the aforementioned properties of a DEDP, different DEDP paths through the state space may be more or less productive.

As shown in Fig. 1 a DEDP in PSI has components, which differ along the dimensions of their changeability. The first dimension is the dynamic character ranging from static, i.e. pre-defined for all possible DEDPs, to dynamic, i.e., subjected to changes in a DEDP. Another dimension is the sphere of visibility or commitment. It ranges from shared, i.e., having the same meaning and instances for all DEDP participants, to subjective, i.e. having specific instances for different actors (though in the terms of a common ontology). Static shared DEDP components are atomic activities, associated software tools, and resources. It is subsumed that the processes are assembled (ultimately) of atomic activities, which are the pieces of the design technology used by the company. The technology normally provided by a design support unit often suggests the usage of a specific software tool to perform the activity. The execution of a given

[17] It should be noted here that this freedom implies more complications in planning, scheduling and the necessity to deal with finer grained DEDP model.

activity consumes certain resource instances in given quantities. The model of a design process is based on the following assumptions. A DEDP is initiated by an external influence providing a goal to a certain actor. This goal is subjectively transformed to a task according to the knowledge of this actor. The actor has his or her subjective knowledge about the composition of the task, i.e. about the sub-tasks and the atomic activities to be performed within the given task. The dependencies between different tasks are also the subjective knowledge of an actor and are formalized in his or her Partial Local Plans (PLP). The actor may decide to perform a sub-task or to execute an activity of a decomposed task himself or to hire (for the price) another actor through the available collaboration mechanism. In the latter case the sub-task becomes the goal of another peer-actor who commits himself to performing the corresponding task by striking the contract deal. Hence the appearance of actor-task combinations in a DEDP is subjectively dynamic. The mechanism of incorporating new actors to the process and the model of the design team are subjectively dynamic as well since they depend on the decisions and choices taken at run time by the groups of actors which states change in the process. Though, the rules of encounter of the mentioned mechanism are shared static and provide the horizontal laws for the system in the form of the set of interaction protocols, types of commitments and a convention [Er04]. According to the aforementioned, a design artifact is a subjectively dynamic outcome of the process, since it is produced by a subjectively dynamic collaborative team of actors. However, the proposed layering allows reaching this effect through applying shared static atomic activities, though in subjectively dynamic combinations. For an activity a design artifact is both the material input and the result of its execution (by a dynamically assigned actor).

The actors who perform a task and initiate collaboration are Task Managers. Their local goal with respect to the performed task is to choose the next step on the process path as productive as possible. Of course an actor needs a sort of productivity assessment model for that (Section 4.2). It is also clear from the given DEDP model outline that its main operational components are negotiation and team formation mechanisms.

4.2 Assessing Productivity by the Earned Units of Welfare

Productivity by its very nature is one of the most important economic metrics and stands for the ratio of the produced output (value) to the consumed input (value). As such it is an integral characteristic of any transformation process, e.g. a DEDP. Neo-classical definitions of productivity impose rigid requirements on the process under consideration. The homogeneity of inputs and outputs is the most severe one with respect to engineering design. Known productivity measurement methodologies in engineering design ground themselves on the assessment of design complexity characteristics in the creation of homogeneous input- and output-measures. They pretend to do it by applying heuristic weights to compared parameters (e.g., the normalized transistor count[18] in Semiconductor and Electronic Systems (SES) design, FP, KSLOC counts[19] in software

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[18] Measuring IC and ASIC Design Productivity. White Paper. Numetrics Management Systems, 5201 Great America Parkway, Suite 320 Santa Clara, CA 95054, 2000
[19] FP stands for Functional Point, KSLOC – for kilo lines of source code.

design, etc.). The fundamental problem of this approach is that the complexity characteristics need to be invariant both to the type of a process and to the transformed design artifact. If they aren't, measurement scales tend to lack well-defined units. Consequently the properties of the measurement scale, the labeling of the units, and the interpretation of the values derived are of very limited practical use. Furthermore in non-deterministic environments, where DEDPs are dynamic and are not entirely under the internal control, such measures are not very reliable even if proposed. If used for business management purposes the quality of decision making can deteriorate enormously. It is therefore important to build the measure which addresses the homogeneity requirement with respect to inputs and outputs and which is invariant to the dynamic characteristics of a process. Such a measure may be based on the integral process success indicators like for example the ratio of the Earned Value to the Planned Value or to the Actual Cost at a Sign-off Stage of the process. This implies that productivity of a DEDP may be assessed by the value produced and accumulated by designers in a team at a certain process stage. The more value produced by a designer the more productive he or she is if compared to the others if several DEDPs are taken into consideration. Hence more productive designers are characterized by the higher volume of accumulated Units of Welfare (UoW) if designers are incentivized adequately to their produced value (subsumed in PSI). It is important that this characteristic is invariant to all aforementioned dynamic features of an engineering design process. UoW is therefore a normalized scalar measure which by its semantics is quite similar to the notion of a Utility which is widely used Distributed Rational Decision Making (e.g., [Sa99]). UoW earning mechanisms in PSI are based on contracting deals stricken through several types of negotiations. The concept of UoW is central to DEDP modeling framework and will be highlighted further on in the paper.

An actor may get (or lose) UoW only through collaboration with other actors in DEDP performance. Collaboration occurs when: (1) an actor out-sources a DEDP task to its sub-ordinate by directive or contracts another actor for a (sub-) task; (2) a design solution is re-used in different DEDPs; (3) a software tool is borrowed to perform a DEDP activity.

These types of encounters are directive assignments, contracting negotiations, and, possibly, group-buy combinatorial auctions for licensing STs. The mechanisms for these encounters comprise the protocol, the strategy and the social norms. The protocol determines the rules of interaction. The strategy determines the pro-active rational behaviour of a participant. The social norms define the commitments of the participants and the binding conventions. Sections 4.3 – 4.5 provide details for negotiations on out-sourcing a task, design solution re-use, and the borrowing of a software tool.

4.3 Negotiations on Out-sourcing a Task

Negotiation on outsourcing a task takes place each time an actor realizes, according to its knowledge of the task or because of the overload, that the task should be outsourced to one of the fellow colleges and the actor believes that several appropriate candidates capable to perform this task are available. Negotiation is performed instead of a directive task assignment in the cases an actor wants to make an optimal (UoW) choice from the

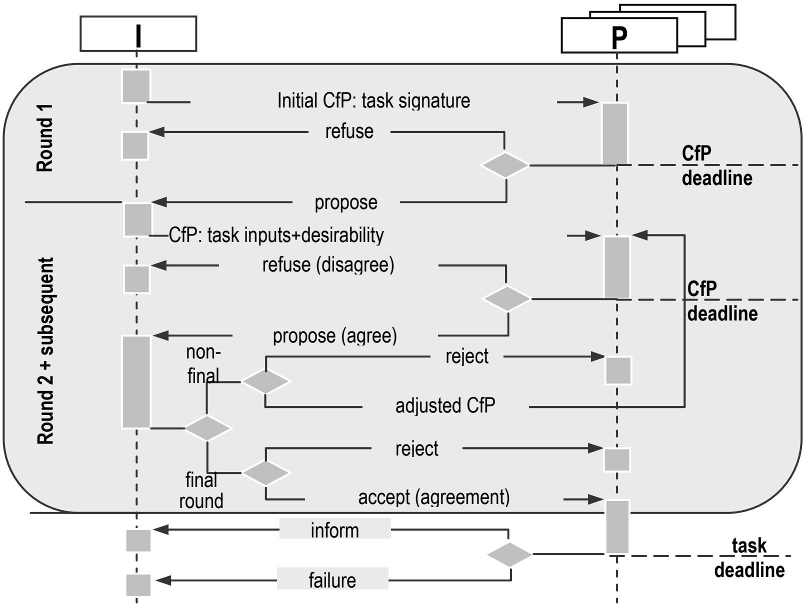


Fig. 2. Extended Iterated FIPA Contract Net protocol for outsourcing a task.

set of the possible contractors. An extension of the FIPA Iterated Contract Net protocol (CNP)[20] is used as the interaction protocol for this type of negotiation (see Fig. 2). A task requestor agent is considered an Initiator (**I**) in this encounter. The actors about which **I** believes that they are capable to perform the task (Fellow Capability Expectation Matrix, FCEM [Er04]) form the party of the invited Participants (**P**).

The first round of the interaction, which is the extension of the FIPA protocol, aims to find out if any of the known capable **P**s may agree to perform the task. Negotiation set for this round contains task signature only (for example, 'Perform FSD'). **I** may start exploring another opportunities of out-sourcing the task if all **P**s from the sphere of his awareness [EP02] refuse in the first round. For example, **I** may require the list of matching freelance service providing agents (SPA) from an Internet public directory (like a web service repository). We shall not go into further details in this direction as far it doesn't add much in the concept.

Negotiation on the second and the subsequent rounds is about the terms of the possible contract. **I** advertises the task inputs and the discrete results desirability function as the incentive (in UoW) over time. **I** than chooses the best **P**s proposal weighted by the respective credibility values [Er04] in case several **P**s proposals indicate the agreement. Subsequent rounds are used to adjust the task inputs or the desirability function in the case if no one of the **P**s has agreed on the previous round. **P**s refusals and propositions are shown in Fig. 3. These feedbacks are formulated in a constructive way to allow **I** to

[20] Foundation for Intelligent Physical Agents. FIPA Contract Net Interaction Protocol Specification. Ref. No XC00029E. 2001. http://www.fipa.org/specs/fipa00029/

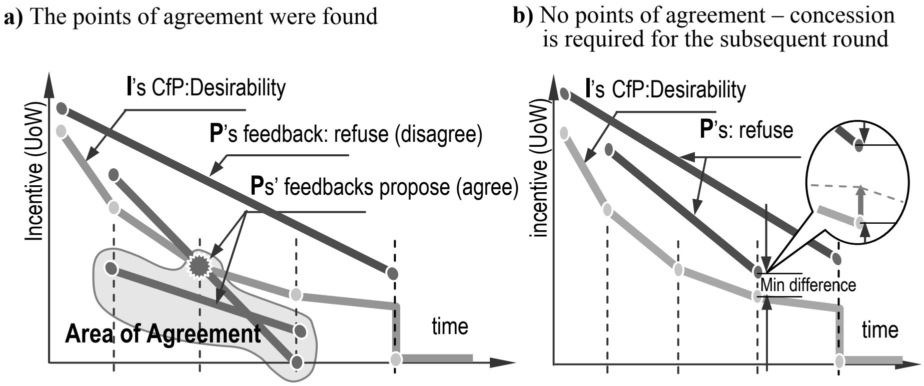


Fig. 3. Negotiation on outsourcing a task: agreement, disagreement, and concession for the next round.

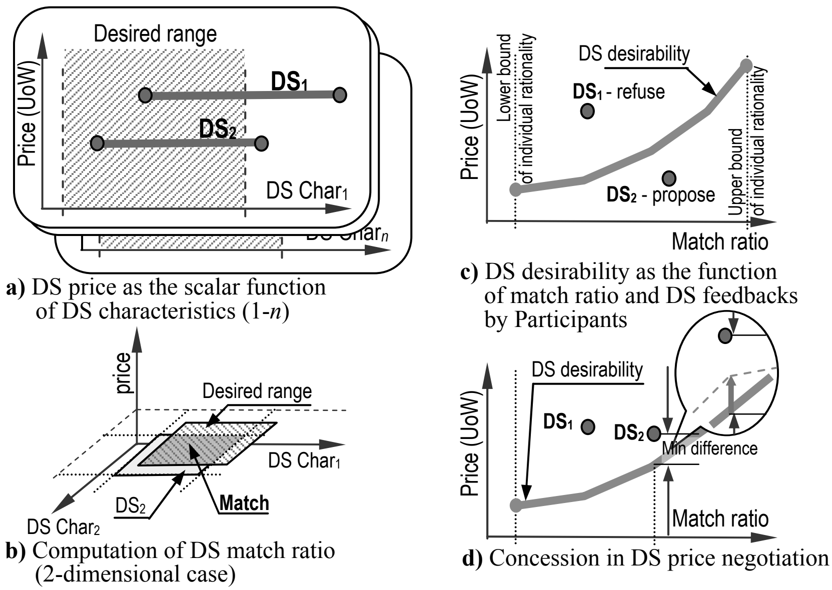
adjust its CfP in the subsequent round. A feedback contains two incentive-time points defining the segment on which a possible agreement may be stricken. More details on how the **P**s may compute their feedbacks are given in [Er02]. Evidently the area of agreement for the current round could be formally defined as the union of all those parts of the feedback segments which are on and below the **I**'s desirability function polyline. All other points of Ps' feedbacks indicate their disagreement with the offer of the current negotiation round. In case in a round n no agreements were detected by **I** it concedes just enough for not to concede in the next round n+1. The concession in incentive value (UoW) is computed as the half of the minimal difference between the current desirability function and the current feedbacks of **P**s. **I** may continue to concede in the series of rounds if: (1) the **P**s concede accordingly in a monotonic way, (2) the concession still makes the possible deal individual rational for **I**. **I** considers the negotiation round as final if it can accept one of the **P**s' agreement and strike the contract deal. The chosen **P** becomes the Contractor and joins the Design Team for the time necessary to perform the out-sourced task.

I may declare the negotiation round as final by repeating the desirability function without concession. Hence, if **P**s do not concede enough to make agreement in the last round, negotiation ends without reaching the agreement. *Negotiation ontology* [EKT02] is used as the formal semantic frame for the contents of the messages agents communicate with while negotiating on out-sourcing a task.

In the cases an actor has no choice or prefers to assign the execution of a task in a directive manner it uses a directive conversation which is the simplified case of the interaction protocol presented above.

4.4 Negotiations on a DS Re-use

Negotiation on a DS re-use occurs when a human designer realizes due to his experience that a DS for his current design might be available at his colleges' or in the corporate DS repository. The designer than instructs his personal assistant agent to perform DS re-use negotiation for him by providing the desired ranges of DS characteristics like, for



a) DS price as the scalar function of DS characteristics (1-*n*)

b) Computation of DS match ratio (2-dimensional case)

c) DS desirability as the function of match ratio and DS feedbacks by Participants

d) Concession in DS price negotiation

Fig. 4. Negotiation on a DS re-use: ranges of DS characteristics, DS match ratio, desirability and concession.

example: input voltage, V (2.5 – 5.4); output frequency, MHz (1.80 – 1.85); linear dimensions: length, mm (20-30), width, mm (10-15); etc. *Design Artifact Ontology* [EK04] is used as the formal mean for representing the shared conceptualization and the terminology for that. Like for sub-task allocation the extended FIPA Iterated CNP is used for this kind of negotiation. A DS requestor agent is the Initiator (**I**) in this encounter. The agents about which **I** believes that they are capable to provide a matching solution are the invited Participants (**P**).

The first round of the interaction, aims to find out if any of the believed capable **P**s may actually have a desired DS in stock. Negotiation set for this round contains DS type only (for example, 'Input Signal Amplifier'). In case no proposals were received back from **P**s at this round **I** will proceed with the design from scratch.

Negotiation on the second and the subsequent rounds is about the terms of the possible contract. **I** advertises the desired space of the ranges of DS characteristics (Fig 4a) and the discrete DS desirability function as the price over the DS match ratio (Fig. 4c). **P**s reply with their DS characteristics ranges and the price of the DS. **I** than computes the match ratio M for each received feedback (Fig. 4b):

$$s_i^{\min} = \begin{cases} d_i^{\min} & \text{if } s_i^{\min} < d_i^{\min} \\ s_i^{\min} & \end{cases},$$

$$s_i^{\max} = \begin{cases} d_i^{\max} & \text{if } s_i^{\max} > d_i^{\max} \\ s_i^{\max} & \end{cases}, \qquad (1)$$

$$M = \prod_{i=1,n} \left(1 + \frac{(d_i^{\min} - s_i^{\min}) + (s_i^{\max} - d_i^{\max})}{d_i^{\max} - d_i^{\min}} \right),$$

where: $s_i^{\min}$, $s_i^{\max}$ - the lower and upper bounds of the characteristic range for the characteristic i of the DS by **P**, $d_i^{\min}$, $d_i^{\max}$ - the upper bounds of the desired characteristic range for the characteristic i of the DS by **I**. Geometrical interpretation of (1) is given in Fig 4b. *M* shows which part of the volume of the desired characteristics space is covered by the space of the ranges of characteristics of the proposed DS.

After the match ratios are computed for each **P**s' feedback **I** proceeds with the DS price analysis as shown in Fig 4c by comparing DS propositions, which are now the points on the Match ratio – Price grid, with its DS desirability function. **I** chooses the best **P**s proposal weighted by the respective credibility values [Er04] in case several **P**s proposals result in the agreement. Subsequent rounds are used to attempt to find the agreement on the DS desirability – DS price in the case if no one of the **P**s has agreed on the previous round. **P**s refusals and propositions are shown in Fig. 4c. A feedback indicates the agreement if the corresponding match ratio – price point lies below or on the desirability function polyline. All other points of **P**s' feedbacks indicate their disagreement within the current negotiation round. In case in a round *n* no agreements were detected by **I** it tries to concede just enough for not to concede at the subsequent round *n*+1. The concession in price value is computed as the half of the minimal difference in DS price between the current desirability function and the current feedbacks of **P**s (Fig. 4d). **I** may continue to concede in the series of rounds if: (1) the **P**s concede accordingly in a monotonic way, (2) the concession still makes the possible deal individual rational for **I** with respect to the upper bound of the price value. **I** considers the negotiation round as final if it can accept one of the **P**s' proposition and strike the contract deal. The chosen **P** becomes the Contractor and commits to provide the DS to **I**. **I** may declare the negotiation round as final by repeating the desirability function without concession. Hence, if **P**s do not concede enough to make agreement in the last round, negotiation ends without reaching the agreement. *Negotiation ontology* [EKT02] is used as the namespace and the formal semantic frame for the contents of the messages in negotiations of this type.

4.5 Choosing a Software Tool

There are principally two possible scenarios for selecting and providing an ST to a designer. The simpler one occurs when the relevant tools are already licensed by the company, the department, or the group under simulation. It is therefore under a human designer's responsibility to choose the tool from the available variety according to his requirements (e.g., his familiarity with the tool, his favorable attitude to it because of the previous successful experience, whatever). In this simple case the tool provision parameters are not negotiated and are not subjected to bargain – the usage price (in UoW) is fixed and may be determined according to the internal policy of the organizational structure. The protocol for this scenario is straightforward and comprises the request from a designer (Mr. Deed), the reply of the STP providing access to the chosen tool, the request from STP charging UoW from Mr. Deed for the usage, and actual UoW transfer by Mr. Deed. The strategy for Mr. Deed is very simple and is to choose the cheapest ST from the subset of the equally most attractive among the available ones.

The more complicated scenario occurs when the required tool is not available and should be therefore licensed. In these settings the STP should ground his necessity to purchase the tool by the unsatisfied demand from designers. From the other hand the designers may form the so-called buyers' coalitions to carry more conviction and to expect the wholesale discounts. A combinatorial auction framework may be used for such kind of scenarios.

4.6 DEDP-MAS Prototype

DEDP-MAS simulator software prototype has been implemented to verify the modeling framework and to assess the feasibility of building an industrial strength tool for DEDP performance optimization through their productivity assessment. Implementation has been done in MASDK rapid prototyping environment [Go04] which supports Gaja methodology for MAS design [ZJW03]. In the evaluation experiments the simulator is used in two application modes: playback and "freestyle" (predictive) simulation. In playback mode the simulation is used to assess the performance of the DEDPs which have been accomplished in the past. Predictive simulation supports project managers in planning and dynamic re-planning of running design projects in cases of several kinds of events which are out of their direct control: late changes to the design objective, sudden unavailability of the team members, the changes in the workload of the designers according to the influence of the other independent projects, etc.

Based on these usage modes current PSI testbed comprises the following two parts. The first part (the initial testbed) comprises the detailed records of the two simplified DEDPs: the design of a digital multimedia encoder [JM04] and the design of an analog controlled amplifier [We04]. For example the complexity of the digital use case is characterized by: 5 designers, 4 functional blocks, 36 performed atomic activities from RTL[21] design till tape-out in GDSII[22] format. These processes have been described according to the data collected by lead designers of Cadence Design Systems GmbH in their previous design projects. Execution logs have been created for the respective DEDPs through filling in the DEDP questionnaires (e.g.,[KW04]) and recording the collected knowledge formalized in terms of DEDP ontologies with the help of the specialized log editor implemented in PSI. These logs are used as the training data for making the task-activity, PLP, belief and self-belief parts of DEDP-MAS agents' mental models and their UoW asset records closer to the reality. Playback simulations performed on these logs demonstrated that the simulator develops DEDPs very closely to what happened in reality. Observed fluctuations were caused by the changes in the parameters of the availability of the team members in the course of the simulation experiments by "screwing" their available capacities. This fact confirms the adequacy of the developed framework to the industrial requirements in SES.

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[21] **R**egister **T**ransfer **L**evel.

[22] GDSII Stream format is the standard file format for transfering/archiving 2D graphical design data.

The second part of the testbed which is under creation covers the prediction capability. A set of 3 to 5 design artifacts of real world complexity[23] is planned to be used for creating detailed project plans by experienced project managers (2-3 per artifact). As the part of this planning process all decisions and their rationale is recorded to extract the know-how of a project manager. Experiments with DEDP-MAS predict the development of the process up to the next checkpoint through the simulation based on the initial task and existing agents' mental models. DEDP-MAS configuration (the set of software agents with the accordingly prepared mental models) corresponds to the project design team. It is assumed in the experiments that only one agent performing the role of the Task Manager for the initial task assists the human project manager. The rest of the agents simulate the activities and the collaboration of the other design team members automatically., In line with the development of the DEDP the human expert repeatedly carries out the following duties in the experiment: gradually develops DEDP log through PSI log editor; analyses the predictions of the further development of the process via interaction with Task Manager assistant agent, and initiates predictive simulation for the part of the process which has not yet occurred. Simulation aiming at prediction of the future DEDP development is initiated after the playback of the log corresponding to the accomplished part of the process at the given point in time. During simulation the human project manager may "screw" the available capacities of the designers and revise the assignments of the activities arranged by the assistant Task Manager agent. Accordingly the project manager can evaluate the predicted path of DEDP in what-if mode trying to gain maximal productivity (in terms of UoW) by finding the optimal combination of the "screwed" parameters. Simulation results are exported in MS Microsoft Project format. This option allows the project manager to compare the Gantt charts of DEDP paths which happened in real life to that predicted by simulation.

5 Concluding Remarks

In middle ages alchemists attempted to make use of the Philosopher's Stone – a mysterious, unknown substance which, as they blindly believed, has the power to transmute base metals into gold. So does contemporary performance management blindly hails IST as its "Magnus Opus". In this paper we tried or best to get conviction that it is high time to build a firm scientific foundation of performance management. We need a consistent framework addressing the relevant aspects of performance management from the abstract level to the concrete level. Only than IST will be able to unfold its full potential, and deliver on its promises. The strategic potential of IST does not lie in empty automation that enforces unrealistic and oppressive processes. It lies in enabling better decision making in a highly complex environment of change, uncertainty, risk, and urgency.

The paper proposed a kind of a rigorous framework for performance management in the sense that it is based on self-evident axioms of various schools of economics. These

[23] Real world complexity means that the mentioned artifacts are designed in current industrial projects which aim to finish up with marketable products.

axioms are then used, along with some rules of inference, to derive several corollaries of interest. That is, the rigor comes from logical formalism. The framework supports modularity and reusability of results in the sense that one can always use results established previously and in different context without having to prove those results from scratch. The starting point of the framework is the definition of performance as a purposeful action. This definition accompanied by the analysis of systems laws and code implies that the paradigms of an action and an agent are the most important in attempting to put performance management and measurement to formal rails. We have demonstrated in the paper how it may be dome through exploiting the paradigm of a software agent. The formal framework for modeling DEDPs and focusing to the assessment of their productivity and to the enhancement of their performance has been presented. The main contribution of this modeling framework is the ability to provide evaluation and prediction capabilities and flexible fine-grained models of a DEDP through self-configuration and self-orchestration of the teams of designers. The mechanisms of self-configuration are based on several types of negotiations.

Our plans for future work in performance management domain are focused to further development of measuring formalisms and to the development of software tools at industrial scale.

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