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# Business Process Model Plasticity: Inclusion and evaluation of the PAR heuristic

Master's Thesis

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# Abstract

In today's rapidly evolving environment, improving business performance is a critical provision for any organization. Heuristic Process Redesign, constitutes one of the most entrenched transactional analytical methods stemming from core ideas behind Lean Six Sigma and BP Reengineering. However, BPR in practice is still less science than art. Practitioners usually recede on best practices when performing Business Process Redesign. Despite the fact that over the past two decades various papers addressed Business Process Redesign and BPR best practices little is known regarding the general instructions when it comes down to applying them. Business process redesign can be implemented with the use of several best practices guidelines, but they still have some limitations in their application domain and/or they are not adopted in a large scale.

This thesis focuses on the Parallelism heuristic, taking into account several handpicked complexity metrics related to it. In order to determine when to apply Parallelism and under which terms it emphatically affects a business process, experiments were conducted on various business processes taken from the existing literature. The aforementioned experiments included:(a) the calculation of the chosen complexity metrics relevant to the Parallelism best practice and then using the Bender method and logistic regression to extract thresholds for these metrics regarding the Plasticity notion of BP models in terms of their eligibility and capability to be redesigned ,and b) questionnaire that was handed out to undergraduate and postgraduate students containing various business process models from the literature (presented with the use of BPMN), postulating questions that if certain tasks could be put in parallel within the process ,instead of remaining sequential, would the process benefit from the changes or not (i.e. identifying the correlation between the metrics and Plasticity , supporting the hypothesis).

**Keywords:** Business process redesign; plasticity; parallelism; best practices; complexity metrics; Bender method; threshold extraction; threshold evaluation; logistic regression; BPMN.

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# Contents

# List of Abbreviations

BPR: Business Process Redesign

BP: Business Process

BPs: Business Processes

BPM: Business Process Management

HPR: Heuristic Process Redesign

PAR: Parallelism best practice/heuristic

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# 1. Introduction

Businesses, organizations, enterprises. They all are process oriented entities with one common goal in mind, the improvement of their respective business processes. In today's competitive environment for businesses in general, improving is a vital urgency for the continuity and growth of any organization. There is a plethora of theories, guidelines and techniques related to process development. In the midst of them, Business Process Redesign (BPR) is considered to be a rapid and efficient way. According to Thomas and Davenport, BPR was defined as :"the analysis and design of workflows and processes within and between organization [enabled by] the capabilities offered by computers, software applications and telecommunications"[1].

Despite the fact that best practices in the field of BPR were developed by different researchers aiming to help different domains, Reijers and Liman Mansar pinpointed 29 distinct best practices regarding the redesign endeavor [2].Although said practices have a wide range of applications in BPR, a set of general guidelines is still missing when it comes down to applying them. In our research the main focus is set upon the Parallelism best practice and the Plasticity notion, a model measure inspired by Neuroplasticity[3].According to Tsakalidis et. al., BP model plasticity is the ability of the process model to be redesigned in response to intrinsic or extrinsic stimuli by reorganizing its activities, connections, structure, or functions [3].

In this context, the first function is to choose an appropriate set of internal BP metrics that relate directly to the Parallelism best practice after having justified our choices. The next step in this project is to correlate these chosen metrics to the Plasticity model and extract thresholds on them by utilizing the Bender method and binary logistic regression. In order to achieve our goals, experiments with the use of questionnaires had to be conducted involving MSc and BSc students studying in the Applied Informatics department.

## 1.1 Problem statement and motivation

Throughout this empirical research, the capital purpose is to discover the correlation between a set of selected internal metrics and the Parallelism best practice under the scope of the Plasticity model measure while eliciting thresholds on the aforementioned complexity metrics of BP models. The literature review acknowledged a significant gap in the topic of Business Process Redesign [2].In short, there are extensive papers on Business Process concepts such as flexibility and agility , but the concept of Plasticity has not been explored thoroughly at this time. Given the fact that Plasticity differs from flexibility and agility concepts, since it reflects models' redesign capability prior to implementation instead of the models' capability to change at runtime[3]. Subsequently, this thesis aims to fill a small gap in order to empower practitioners in the field of BPR when it comes to applying the Parallelism best practice by supporting them with a functional framework, including concrete guidance by signifying the probability of a given model to be a viable candidate for redesign initiatives by implementing this particular best practice.

## 1.2 Research Aim & Objectives

Therefore, the following research aim is addressed in this thesis:

**"Which complexity metrics should be chosen that directly correlate to the model of Plasticity of a process model in order to evaluate it, by extracting trustworthy threshold values for these metrics regarding the aforementioned evaluation, and the probability of whether it should be redesigned by implementing the Parallelism heuristic."**

By assessing this fundamental research goal, this thesis extends the research in the following ways. To the extent of quantifying the capability of models to be redesigned, a direct correlation between the plasticity of models with the applicability of redesign heuristics, especially Parallelism which is a specific form of the RESEQ heuristic, is expressed. Specifically, the following assumptions were made:

a) A model's Plasticity can be assessed by choosing a suitable subset of internal measures prior to applying one of the best practices , in our case Parallelism, specified in [4].
b) Working out the probability for a model to be efficiently plastic, namely its eligibility to be redesigned by implementing the PAR heuristic.

The main research objective of this thesis is to correlate specific internal model complexity metrics to the Plasticity model measure, extract thresholds on these metrics by utilizing binary logistic regression and the Bender method, address the capability of models to be redesigned in terms of their total number of constrained activities and to calculate the probability of a model to be (in)sufficiently efficient plastic prior to the implementation of the Parallelism (PAR) redesign heuristic.

In order to reach a feasible solution to this problem, we need to understand it and resolve the following questions in depth.

## Research Question 1

Over the past years, various approaches have been submitted aiming to schematize BPR that hinge on steady process monitoring and analysis[3].Recent advances in process mining and analytics were key factors in furthering the effectiveness of BPR, with the latter being directly related to Big Data and its influence on the way that organizations discover, monitor and improve their processes[3].As a result, this left a considerable gap in current literature regarding the redesign capability of BP models and its evaluation, preceding the implementation of redesign methods[3].Therefore, the first question is formed:

**RQ1**. "Why do we need to propose a new approach in order to successfully motivate redesign upon BP models?"

## Research Question 2

According to Dumas et. al.[4], there are different methods in order to induce the desired redesign upon a BP model. For our project we decided to select Heuristic Process Redesign (HPR) and specifically BP behavior, instead of any of the other methods. Hence, the second question of this thesis is postulated:

**RQ2.** "Which are the reasons that led us to choose HPR focusing on BP behavior, over any of the other methods available?"

## Research Question 3

Given that Plasticity is a newly introduced concept in the field of BPR[3], our first concern is to indicate the differences between the model of Plasticity and other related measurable concepts that exist already. Consequently, the third research question can be formulated as:

**RQ3.** "Why Plasticity needed to be introduced as a new concept in the field of BPR, and in what ways is different than any other related measurable concepts?"

## Research Question 4

BP models exhibit different measurable concepts such as complexity, density, entropy and quality. These concepts are indicated on a critical level by their respective internal measures. Among them complexity is the most measurable feature [5] appearing quite often in scientific literature, where numerous definitions prevail [6].In agreement with [7],BP model of complexity is defined as "the degree to which a system or component has a design or implementation that is difficult to analyze, understand or explain" [7], which lead to the inevitable conclusion that a model complexity is not possible to achieve by using only one type of metrics[8], fact that led to the systematic analysis and identification of 65 different process complexity metrics [9], [10].Therefore the fourth research question is as follows:

**RQ4.** "Which of the model complexity metrics should be chosen that are related and relevant to the applicability of the Parallelism heuristic?"

## Research Question 5

Extracting thresholds is a complex research task, given the fact that it requires both practical and theoretical backgrounds of knowledge. Among researchers and software engineers no method is widely accepted as the most effective one in threshold extraction. As stated in [11] a wide variety of methods serve this purpose, which leads us to the fifth question:

**RQ5.** "Which of the methods available for threshold extraction (for BP measures) should we utilize to achieve the desired goal, and why?"

## Research Question 6

After our proposed framework has taken form and the required experiments were conducted there is one last question to ask, which is the following:

**RQ6.** "How well did the framework behave in terms of achieving the desired goals?"

By answering the above-mentioned questions, the combined outcome will provide a solution to the defined problem statement.

## 1.3 Research Methodology & Thesis Outline

The research method that will be used throughout this thesis is a slightly modified version of "The Regulative Cycle" that was developed by P.J. Van Strien [12] and includes 5 steps ,as shown in the following schema (Fig.1).

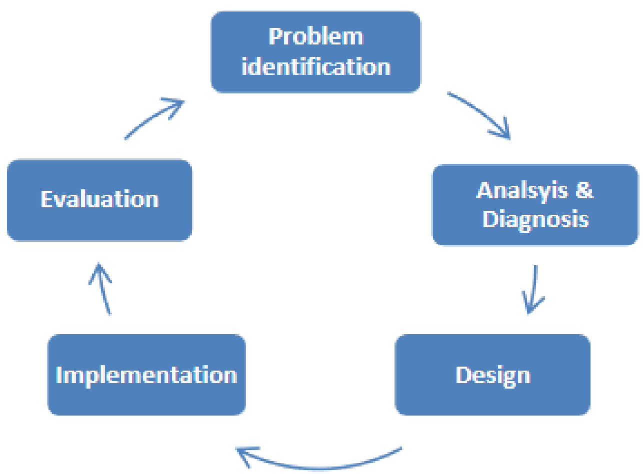


Figure 1: The Regulative Cycle [12]

Therefore, in order to carry out our research purposefully, we went through the following stages:

1) **Selection of Redesign Heuristic(s)/Best practice(s):** In this case the Parallelism (PAR) best practice is selected, among the 29 heuristics available and are listed in [2], [13].
2) **Internal model measures are selected:** Metrics that directly relate to the PAR heuristic and its applicability, are elected in this step. The list is not exclusive, meaning that more metrics could possibly be related to PAR.
3) **Calculation of the elected metrics:** In this step every metric selected is calculated for every process model participating in the experiments.
4) **Experiments are carried out:** The subjects provided us with the desired experimental data (Correct Answers, Time elapsed, Efficiency and personal opinion regarding plasticity).

5) **Performing Pearson correlation analysis:** The goal of this step is to check for any possible correlations between the elected metrics and plasticity. We opted to choose the Pearson correlation over the non-parametric Spearman correlation, given the fact that our primary hypothesis is that the elected metrics portray linear correlations to plasticity, time and correct answers provided by the subjects.
6) **Application of the Binary Logistic Regression mathematical method:** The average efficiency of plasticity, is the response variable. Coefficients $\alpha$ and $\beta$ are extracted as well from the formula.
7) **Distinct levels of plasticity are established:** This step is conducted based on the probability of acknowledging the model as efficiently plastic.
8) **Implementation of the Bender method:** Value of an Acceptable Risk Level (VARL) is computed for every probability.
9) **Practical evaluation of the produced thresholds:** With the use of process models from literature, the resulting thresholds regarding plasticity are assessed.

# Problem Identification

It is the most important step of this process, where the problem is identified and defined thoroughly (Ch.1).

# Analysis & Diagnosis

In this step of the process, related literature and/or work to the defined problem will be reviewed extensively as well as identifying the gaps in the area of quantifying a model's eligibility and capability to be redesigned before any changes are applied (RQ1).

During the Analysis stage, the following will be addressed in depth (Chapters 2 ,3):

- The methods that can be used to induce redesign endeavors upon BP models.

- Measurable model measures such as Plasticity, Flexibility, Agility.

- Best practices and their impacts on performance dimensions [2].

- Model complexity metrics as they appear in [9], [10].

- Threshold extraction approaches [11].

# Design

At this point of the Regulative Cycle, the form of our proposed framework is construed. Specifically, it focuses on the BP behavior aspect of the HPR redesign method and specifically on the PAR heuristic with the sole purpose to correlate certain complexity model metrics to the Plasticity model measure, in order to assess a BP model's capability to be redesigned by extracting thresholds for these metrics, after the use of logistic regression and the Bender method (RQ2-RQ5). The design will be presented in the 4$^{th}$ Chapter of this thesis.

# Implementation & Evaluation

The last two phases will provide the answer to the last research question (RQ6). The proposed approach is implemented into BP models taken from literature where its feasibility and validation are debated later on (Ch.6).

Finally, a deliberation on the framework's conclusions and limitations as well as ideas for future work concludes this project (Ch.7).

# 2. Overview of Redesign Approaches

In this chapter, a thorough review of the related literature and work will be enacted. Beginning with analyzing the methods that support redesign efforts on BP models, such as Lean Six Sigma and BP Reengineering. Followed by a brief analysis on the Plasticity model measure and similar concepts, while pointing out the main differences between them and prompting the necessity of introducing it. The next subsection in this chapter, presents the well-investigated area of internal model measures and particularly complexity including the 67 different complexity metrics classified in [10].At this point, a short review of the BPR best practices[2] is provided focusing on the Parallelism best practice. Lastly, a concise revision of the methods available in threshold extraction is given to highlight their differences and assist in the selection of an appropriate and validated method for this research.

## 2.1 Business Process Redesign Methods

According to Dumas et.al., BP redesign methods can be categorized as a spectrum and its visualization is defined as the Redesign Orbit (Fig 2)[4].

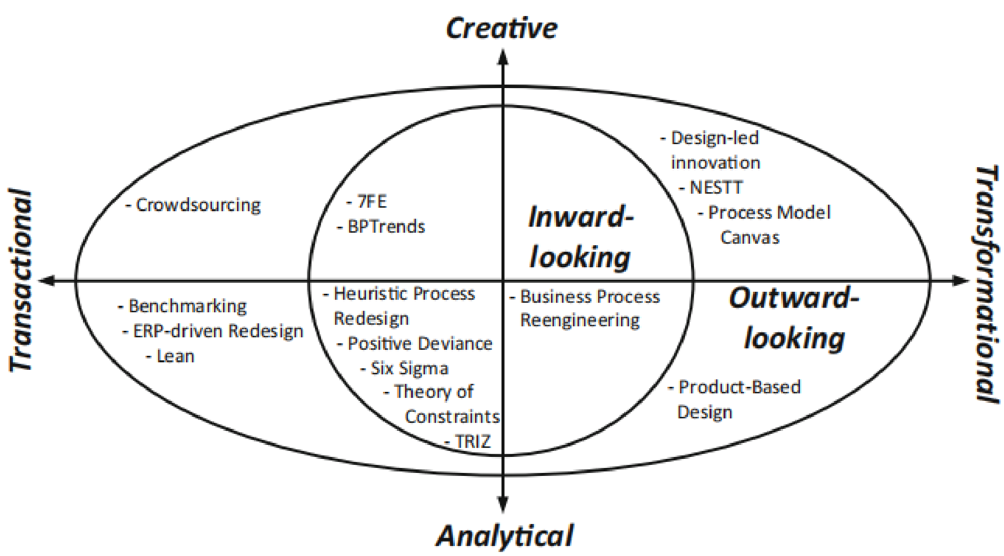


Figure 2: The Redesign Orbit [4]

The vertical axis separates *transactional* methods positioned on the left-hand side, from *transformational* methods on right-hand side[4]. In a similar manner the horizontal axis in the Redesign Orbit, indicates the differences between *analytical* and *creative* methods[4]. All the methods that are considered *inward-looking* are accommodated inside the inner circle of the Redesign Orbit, whereas on the other hand any other method not inside the circle is considered *outward-looking* [4].These three axes in the Redesign Orbit, represent three fundamental notions respectively: the underlying *ambition* supporting the method, the *nature* of the means it demonstrates actively and the *perspective* assumed on the business process[4].In order to understand better what these axes represent, a brief explanation will be given at this point.

## Transactional & Transformational Methods

The magnitude of the change that a redesign method aims to induce, directly refers to the *ambition* behind it. Thus forming the distinction between *transactional* and *transformational* methods[4].*Transactional* methods pinpoint problems and/or bottlenecks inside processes and then provide assistance with solving these issues in increments. Meaning that a transactional method seeks gradual improvement of the overall process, instead of challenging its existing foundations [4].On the other hand the leading objective of all *transformational* methods is to achieve a breakthrough, an ambitious scale advance[4]. These aforementioned methods break away ,in a radical manner, from fundamental assumptions and principles behind existing processes by disputing them [4].

## Analytical & Creative Methods

Another difference that can be spotted on redesign methods is with respect to their *nature*, with analytical and creative methods being on the antipodes of the axis [4]. The main characteristics of any *analytical redesign method* are: the use of quantitative methods and the fact that it has a mathematical basis. The core idea of these methods is to analyze process insufficiencies or to create process alternatives, by employing mathematical tools in order to support their various stages [4]. *Creative redesign methods*, by contrast, are defined at their core by human ingenuity or inspiration and usually are built on the advantages gained via the *group dynamics* aspect: Generally within the environment of a workshop, people stimulate each other in order to come up with new ideas on organizing a BP [4].

## Inward & Outward looking Methods

The last discernable factor, is the *perspective* which refers to the “point-of-view” taken from the redesign method. When the viewpoint of the organization that hosts the BP is assumed, we are referring to *inward-looking redesign methods*. These methods place the concerns and interests of that organization on the spotlight, including any information gathered about the process deriving from within the organization [4].On the other hand, we have *outward-looking redesign methods* which are commonly motivated by opportunities and developments outside of the organization that is currently redesigning. In this occasion an outsider's point of view is assumed, typically that of a customer or even a third party [4].

At this point two important notations must be made[4]:

- The axes on The Redesign Orbit are *orthogonal*.
- Some of the redesign methods have evolved from others. For instance, HPR derived from *Lean* and *Business Process Reengineering*.

## 2.2 Transactional Methods

In this subsection, the various transactional methods that appear on The Redesign Orbit (Fig.2) will be discussed briefly. Once this review reaches its end, Heuristic Process Redesign will be addressed in more detail.

### Analysis of Transactional, Analytical & Inward-Looking Methods

#### Six Sigma

Setting our main focus on the transactional part of the Redesign Orbit, we deduced that it can be broken down on a smaller scale by using the *nature* axis which separates analytical from creative methods[4]. Apparently the most eminent example among analytical methods is *Six Sigma*, in this context. Its foundation lies on the fact that a group of process performance measures are being monitored carefully for deviations regarding a target value, while the main goal is to recondition any deviations to a small fraction in percentage compared to the desired results [4]. Therefore, it consists of a large subset of methods to quantitatively analyze and determine the origin of encountered deviations by highlighting the use of statistical tools to ascertain their size. Leading to the fact that, Six Sigma aims its attention at classifying and validating process improvement contingencies instead of generating detailed redesign methods [4].

#### Theory of Constraints

Continuing our analysis on analytical redesign methods, the following is a notable method that is directly linked to the *Theory of Constraints* (TOC), which is based on a simple principle: Any production setup is restricted in terms of reaching its goals, by at least one constraint [4]. Therefore, in order to improve the overall productivity of the system, said constraint needs to be lifted. If the constraint-lifting process was successful , the intrinsic performance will improve but another constraint will be revealed at a later step of the process [4].Meaning that identifying and lifting a constraint is a repetitive procedure, leading to the conclusion that TOC accentuates on process improvement as a continuing process. Examples of constraints relevant to specific BP circumstances may be: accessible equipment and/or infrastructure, the peoples' skillset that are participating in the process and the protocols that regulate its execution [4]. TOC takes advantage of a variety of tools, in order to help team members with assessing performance problems and solving them, while highlighting the logical connections among the conclusions of these tools as support for decision-making and validation [4].

### TRIZ

This redesign method surfaced as a universal problem solving approach, in an effort to discover how product novelties transpire [4]. Genrich Altshuller, creator of TRIZ, investigated more than 40,000 patents, reaching the conclusion that innovations are motivated by each other through an evolutionary path of patterns. As an illustration, such a pattern can be the integration of a system that has exhausted any possibility to be significantly advanced further, to a super-system as part of it in the following step[4].In an effort to improve systems, services and specifically BPs, several researchers have gathered the TRIZ patterns to try and transform them into helpful tools for that matter. Methods that emanate from TRIZ all share the analytical factor, particularly the use of an explicit subset of principles in order to create redesign alternatives [4].

### Positive Deviance

Positive Deviance is a concept of process redesign targeted towards recognizing and making use of deviant conduct, within departmental circumstances. Based on the assumption that individuals or groups of people sometimes operate willfully in a distinct manner than what is expected of them, but with exceptional positive results[4].As such Positive Deviance has the potential to be used as a scheme to expand that behavior and optimistically produce the same or similar results, while its approach can be built either on qualitative or quantitative methods[4]. A compelling point of this approach, is to form an established link among the motive, the actual behavior and the desired result. Leading to the conclusion that, relevant measures need to be delineated accurately along with installing the links between them[4].

## Analysis of Transactional, Analytical & Outward-Looking Methods

The methods that were discussed briefly in subsection 2.2.1 are categorized as transactional, analytical and they all assume an inward-looking perspective. Naturally, at this point we shall focus on the analysis of Transactional, Analytical & Outward-Looking methods. Such methods are Benchmarking, ERP-driven Redesign and Lean [4].

### Benchmarking

Benchmarking in the BPM framework mainly refers to a composite term ,addressing a range of approaches [4]. Their capital purpose is to examine competing schemes for a specific BP and to implement the best possible choice among them, in terms of relevance and criteria set upon by an individual firm. Theoretically organizations are able to conduct a benchmarking study on their own, although in common scenarios the comparison is carried out by standardization institutions, IT solution providers or consultancy companies which then develop *standardized* versions of BPs for a specific industrial field [4]. These regulated processes are often referred to as reference models, blueprints, industry prints or even best practices. Information Technology Infrastructure Library (ITIL) and the Supply-Chain Operations Reference Model (SCOR) are two characteristic examples of such reference models. Standardized processes are highly attractive to firms in the sense of decreasing the effort towards developing new processes or altering existing ones [4]. There is also the motion, that these pre-packaged BP schemes are somewhat better when compared to what individual firms can produce. Lastly the way of how an industry tends to particular critical processes is reflected on these designs to some extent, meaning that their setup is rather typical, which in turn explains the transactional nature of the Benchmarking method [4].

### ERP-driven Redesign

A distinct variation of the Benchmarking method is, when a redesign endeavor is led by an enterprise IT system, which presumes that crucial BPs assume distinct forms. Specifically when an organization begins the process of implementing an ERP system such as SAP, Microsoft Dynamics ERP or even Oracle ERP [4]. ERP systems belong to the standardized software category, based on unified databases and they incorporate various elements which aim to support key business functions, such as finance, purchasing and human resource management. The pivotal observation for BP redesign, is that the logic supporting the ERP elements already presumes on a large extent how the BPs they intend to support are supposed to be organized [4]. Quite often this logic is ingrained in the software's vendor conception of how BPs are commonly coordinated in particular fields of industry.

Meaning that by adopting an ERP software, organizations essentially also accept the vendor's point of view on how precise BPs should be systematized [4]. The latter is the link to the benchmarking approach that was discussed on the previous subsection. Over the past years ERP systems have evolved significantly in order to become more "process-aware", meaning that it is becoming easier for firms to readjust these systems to their particular needs. Therefore it seems fair to say, that any endeavors made by an organization prior to implementing an ERP system are directly related to that system's range of capabilities and the organization's internal aspects [4].

### Lean

The last transactional, analytical and outward looking method to be discussed is Lean. It has two main objectives when it comes to improving business activities: advance business activities on the (1) overall business level and (2) on the operational-oriented BP level [4]. This method relies on value-stream mapping, which is a tool that its main purpose is capturing entire value chains. The primary notion in a Lean protocol is that value streams will surely show the way of how value is generated from a client's perspective. These value streams need to be mapped in order to point out any dependencies between processes and ,if it is feasible, mold them into Just-In-Time dependencies [4]. The list of stock declines when crude materials or sub-assemblies are transferred from one process to the next this way, while waste elimination constitutes Lean's leading target on the operational BP level. In these initiatives customers' benefits are in the center, meaning that respective process activities are evaluated on whether they add any value or not from a customer's point of view. The latter explains why this method is considered as outward-looking and highlights the term "voice of the customer" which has become permanent [4]. It is also noteworthy, that the encompassing Lean Six Sigma method derived from Lean's fundamentals aiming to improve processes and the fact that they are often used consecutively after the process evaluation activities of Six Sigma [4].

## Analysis of Transactional, Creative & Inward-Looking Methods

In this subsection we center our attention on the *creative* counterparts of the transactional redesign methods, that were discussed previously. Methods like Six Sigma, Benchmarking and TRIZ rely on statistics, make use of mechanisms and are actively justified in amassing information gathered from entire industries [4]. In comparison to the analytical approach, a more regular perspective to ignite process redesign for many corporations is unleashing the creativity of people. The Redesign Orbit (Fig.2) contains two methods that symbolize a wide collection of analogous methods: 7FE and BPTrends. These methods follow comparable steps and logic in order to induce redesign on processes by bringing people together that possess knowledge of an existing BP through a course of seminars [4].Generally the people engaged in, are the representatives of diverse business roles and functions which in turn are related to specific business backgrounds. Ordinarily led by a professional coordinator, seminar members point out process weaknesses, investigate the fundamental premises of the process and produce ideas to improve its weaker features. In the direction of sparking new ideas, various creative techniques are employed: brainstorming, SCAMPER or group ideation [4]. Individuals are encouraged to write down their ideas on post-it notes, which will be presented later on to the rest of the participants on whiteboards, in order to analyze which ones are synergistic and relevant to the improvement of the process in question. Patented versions of this category of redesign method have been advanced by all of the big consulting firms, which are then offered to their respective clients accompanied by the coordinators that are proficient in applying them [4].

## Analysis of Transactional, Creative & Outward-Looking Methods

Previously we explored two methods (7FE, BPTrends) that are inherently inward-looking and highlight the engagement of professionals with a specific role inside a BP. With the appearance of *crowdsourcing* and *open innovation,* it has become increasingly easier for corporations to tap into skills and expertise of people outside their managerial boundaries [4]. Consequently, this may change the course of how the redesign process occurs, even to the extent that it will contribute to an outward-looking variant of a transactional, creative redesign method. Currently this section of The Redesign Orbit (Fig.2) does not contain any fully formed method, but it is relatively easy to deduce how clients and distributors may encourage the identification of BP weaknesses and the creation of improvement ideas [4]. It is quite possible of course, that the assortment of external data and outlooks will need to be connected to the equivalent internal counterparts and endeavors in order to spark beneficial changes for any process. As expected these methods will veer the attention diametrically ,from internal, to external viewpoints making them outward-looking, despite the fact that they are centered on people [4].

## Heuristic Process Redesign

In contrast to the approaches discussed previously, the use of seminars (or workshops) is not an essential element of the Heuristic Process Redesign method. Having a wide range of redesign principles at its disposal and their methodical examination being a priority, it is then categorized as an analytical technique. In fact, this wide collection of redesign heuristics is where the power of Heuristic Process Redesign comes from [4]. In order to better understand this method, our main focus will be on the technical difficulty of producing a new process design. Starting with summarizing the stages required followed by the analysis of its most substantial element in detail later on, the redesign heuristics (Ch. 3.1) that play an integral role on the Design stage [4].

1. *Initiate:* The redesign setup takes place during this stage. Several organizational concerns need to be addressed, such as choosing the project participants. However, from a vocational point of view the most imperative objectives are: (a) to comprehend the current circumstance and (b) to appoint the performance targets related to the redesign project *[4]*. In the interest of achieving both of these goals, (a) can be resolved with the use of various modeling and analysis approaches in order to reach a realization regarding bottlenecks, performance problems and development chances. To obtain a better image for (b), the Devil's Quadrangle is a great aid and will be discussed later on (Ch. 3) *[4]*.
2. *Design*: In this stage after taking into account the conclusions of the Initiate stage, a definite list of redesign heuristics is employed to regulate possible enhancement actions on the current process. For every performance target set on the Initiate stage, there has to be a collective and/or individual observation on relevant redesign heuristics that can be practiced *[4]*. If a redesign heuristic helps with achieving the requested performance advancement of the process under revision, it is considered as desirable to apply. After concluding on those that may be beneficial, it is logical to observe if they can form clusters. In consideration of applying heuristics together, it may be logical for some of them, but not all of them can be applied successfully with others. If , for instance, a decision was made to automate a specific activity, empowering the initial resource that carried it out is pointless *[4]*.In terms of relevant clusters, a collection of scenarios is then produced, each one of them illustrating which heuristics were implemented in them respectively, and essentially how this was achieved. As an illustration, if the heuristic that automates an activity is employed the specification of which activities are subjected to it, is mandatory. Consequently, these scenarios should be perceived as alternatives for the process redesign *[4]*.
3. *Evaluate*: This stage involves the evaluation of the distinct scenarios that advanced in the preceding stage. The evaluation process can be conducted either in a qualitative or in a quantitative manner. Although realistically a combination of the two is used in most occasions, where the appeal of these scenarios is evaluated by an advisory board and later on simulation studies are brought in to establish the selection of one specific scenario for further advancement, quite possibly all the way to its implementation *[4]*. On the other hand, a

possible outcome of this stage is that none of the scenarios are appealing enough to pursue further or are perceived as effective enough to induce the desired performance increase. Either way contingent upon the specific outcome, the final decision might be to re-adjust the performance targets, return to the Design stage or even abandon the redesign project completely *[4]*.

## 2.3 Transformational Methods

Following a similar manner of presentation, we shall now discuss the existing transformational methods that populate the right-hand side of The Redesign Orbit. After a quick glance we notice that less methods exist in this part of The Redesign Orbit, each one of them will be thoroughly discussed in order to complete our literature review regarding redesign methods.

### Business Process Reengineering

Business Process Reengineering is generally considered as the starting point of the redesign of BPs and the first attempt to point out lasting models for this effort. The groundwork for this method was laid by the deceased Michael Hammer at the start of 1990s, and one of the ideas contained in its core is presuming a clean slate for the design of a BP [4].Specifically, as Hammer expressed it in his own words:

“For many, reengineering is the only hope for breaking away from the antiquated processes that threaten to drag them down.”

Meaning that, with the appearance of Business Process Reengineering process redesign set out essentially as transformational seeking breakthrough type of alterations. The main focus of Hammer’s research was to study an amount of businesses that were under pressure but recovered and in some occasions flourished even, including the famously known case study of Ford Motor Company [4]. After having concluded the analysis of these businesses, he extracted three main observations. The first one of these was, that a firm’s success does not originate from relying on gradual improvement of what was already achieved. To put this in plain terms, strong ambition is the key factor in reaping large rewards. The second observation states the necessity to go above and beyond the automation provided by Information Technology (IT), while highlighting the fact that it is a pivotal piece in BP redesign [4]. Therefore, Hammer encapsulated these two observations in the following statement:

**"We have the tools to do what we need to do. Information technology offers many options for reorganizing work. But our imaginations must guide our decisions about technology— not the other way around. We must have the boldness to imagine taking 78 days out of an 80-day turnaround time, cutting 75% of overhead, and eliminating 80% of errors. These are not unrealistic goals. If managers have the vision, reengineering will provide a way."**

The third and final insight, lies in the organizations' need to regulate their work in such a manner to enable a more unified, cross-functional way of conducting BPs breaking away from subsets of intrinsic standards. Adopting a new set of distinctly-defined rules is mandatory and the dependence on this set , in comparison to the collective efforts of a group of people generating redesign ideas, is why Business Process Reengineering dwells on the analytical method section of The Redesign Orbit [4]. Furthermore, the fact that it functions within the sphere and context of the existing BP it intends to redesign, characterizes Business Process Reengineering as an inward-looking method. Dissimilar to the transactional methods discussed earlier and due to its pioneering nature, the principles involved in Business Process Reengineering are not ingrained in an unequivocal analysis on how process redesign is implemented [4]. These principles directly correlate to the technical challenges that arise, when creating a new process scheme. When process redesign was conceived, persuading people of its feasibility was more important rather than establishing it [4].

### Design-led Innovation (or Design-Driven Innovation)

It was noted previously, that the existing transformational methods are significantly less when compared to their transactional counterpart. Despite this imbalance in numbers, transformational methods are indeed being adopted by firms and even new ones come into sight frequently [4]. Some of these methods even managed to reach a popular status without focusing on BPs in the first place. Applications for these methods which are process-specific, were developed at a later point once an initial focus was set upon products or entire organizations, with Design-led Innovation being a characteristic example [4].Its primary purpose is to help organizations with comprehending the deep sentimental ties that prosper between customers and their products. Design-led Innovation embodies a simple principle : form and function of a product are not the only factors which benefit people , they benefit also from the experience conjured by its usage [4]. Following this assumption, companies are incentivized to seek innovations not anticipated by customers, but after given enough time they become enthusiastic of. The creator of this method, Roberto Verganti, studied for 10 years successful companies such as Nintendo and Apple. In detail it passes through three key stages:

listening (obtaining knowledge on individual needs), interpreting (incorporating the knowledge gained on the listening stage with the company's potential) and addressing (getting clients ready and upholding socio cultural change) [4]. Concluding our analysis on Design-led Innovation, its critical facets are: (1) profound change, hence why this method is considered as transformational, (2) obtaining vital knowledge in the listening stage, through the customers' chain making this method outward-looking, and (3) the fact that it depends on the resourcefulness of scientists, designers, and artists, which highlights its creative nature. Specifically suitable BPs to be improved by applying Design-led Innovation are those where client interplay is a key aspect, leading to new ways of how companies interact with their clients will lead to a more wholesome and worthwhile understanding [4].

### Business Model Canvas

Alexander Osterwalder and Yves Pigneur pioneered an inspirational and transformative model for a method to induce process redesign, *The Business Model Canvas*. Essentially it is a visual chart that depicts the relation between an organization's value proposition and its foundation, clientele and fiscal framework. By supporting the strategic assessment of significant organizational features, becomes notably valuable when it comes to developing and evaluating new value propositions [4]. Therefore, the Process Model Canvas (Fig.3) has been formed in such a way that permits companies to debate on the value proposition, which is directly linked to their BPs, in a discernible manner. At a first glance, there are blank spaces under the different headings, which are to be argued and eventually permeated during a series of seminar sessions [4]. The wow! factor (right-hand side of the figure) supporting a BP is the starting point in terms of debating on and utilizing properly the canvas, i.e., what the participating persons in such a seminar anticipate would genuinely excite the existing and potential future customers. The next phase entails the use of this insight in order to resolve what is essential for its installation, meaning the major steps that need to be taken towards this goal in the BP and the vital information to support these [4]. The why? factor (left-hand side of the figure) directly refers to the connection between the BP and the strategic focus of the company. Therefore, Process Model Canvas derives from the customers' expectations to conceive a seminar-based development model for the process under revision with the use of a visual aid, characterizing it as a transformational, creative and outward-looking method [4].

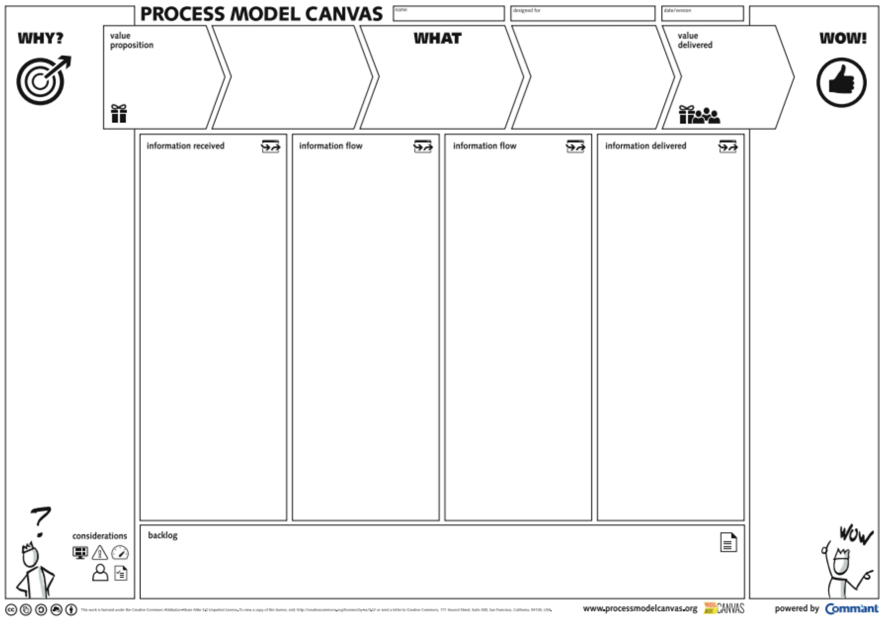


Figure 3: The Process Model Canvas [4]

## NESTT

NESTT is the most recently added method to the spectrum presented with the help of The Redesign Orbit (Fig.2).As a redesign method it has been developed at Queensland University of Technology and its acronym stands for the main phases it involves, encapsulating them: Navigate, Expand, Strengthen and Tune/Take off [4]. Its paramount trait being how the group (8 to 10 people) of individuals involved in a seminar environment exploit the dimensional affordances of an allotted room (Fig.4). While utilizing every wall in the room, including the floor as well, their task is to envision and focus on different angles of a specific BP. Beginning with devising a concept of the new process, which could be stimulated by benchmark companies or vendors of new technologies, awarding NESTT its prominent outward-looking outlook [4]. According to Fig.4, the future dimension assumes its form over three distinct time horizons: 20 days after NESTT was adapted, 20 months following that moment and 3 years (assuming a starting point in 2021). The participants engagement to this concept, dictates the way of overcoming obstacles and seizing opportunities in order to accomplish it, while employing the insights of the existing process (The Now), accessible and necessary resources, along with appropriate strategies. This method capitalizes on a wide range of approaches to assist people with designing a new process collectively, fact which deems it as actively creative in its core [4]. Despite the importance of the interim results, NESTT is a transformational method as a consequence of the comprehensive viewpoint it harbors [4].

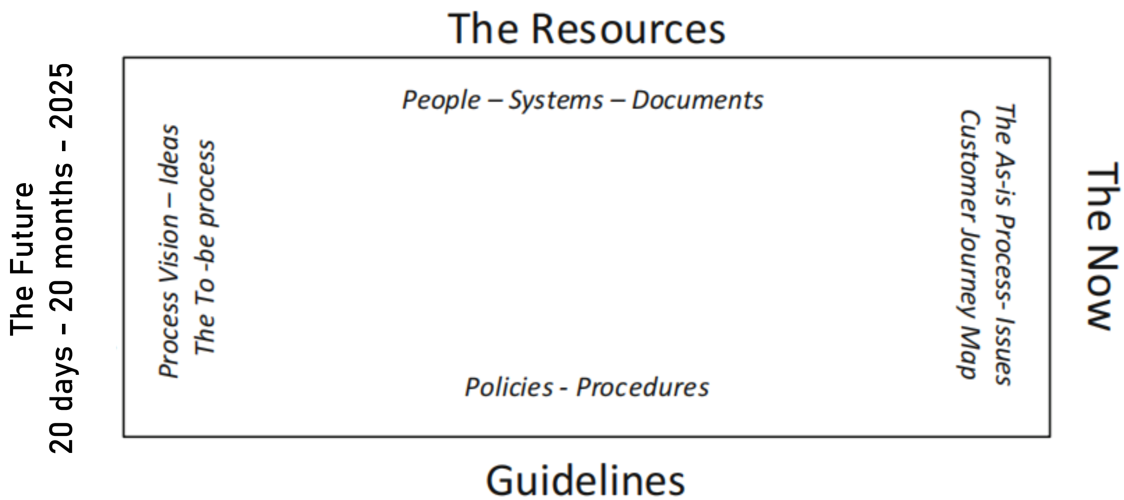


Figure 4: The NESTT room [4]

## Product-Based Design

This method was established at the Eindhoven University of Technology in the beginning of the century. Its ambition is to improve a BP completely rebuilding it, by relying on an academic, practically algorithmic way altogether of achieving its purpose. Therefore it is characterized as transformational and analytical in essence [4]. The outward-looking aspect of this method can be deduced by contemplating its centerpiece, which is the product that a BP intends to deliver. This process involves in fact, exploiting the features of that specific product (or service) in order to figure out an improved design for the process [4]. Clarifying the last statement in more detail, Dumas et.al. suggested the following example [4]: If the end-goal is the production of a red electric car with four wheels, its production process will surely involve assembling or purchasing a chassis, attaching the four wheels to that chassis, mounting the batteries at a later stage and eventually painting the vehicle red (if the acquisition of red parts is not possible). As the case may be, one might not be sure in what order these steps need to be completed, but he could possibly single out a few legitimate dependencies at the very least. Namely, the painting of the vehicle should happen after the acquisition of the chassis.

Summarizing, the underlying notion behind Product-Based Design is to produce the most advantageous process possible, by simply focusing on the characteristics of the product while ignoring completely the existing process [4]. Comparing this method to transactional redesign methods, Product-Based Design is more ambitious in nature but also has a more limited utilization capacity. It was developed primarily to compose processes that produce *informational products*, which in turn are examined and recorded in *product data models*. A process designer then, uses the product data model as a means to work out the best process model for creating and delivering that specific product. Accepting the fact that numerous ways to produce an informational product exist, Product-Based Design divulges observations to all of these possible scenarios [4].

## 2.4 Chapter Summary

In this chapter we reviewed the entirety of redesign methods which are immediately available on the current literature in the field of BPR. These methods were categorized based on their nature and later on studied with the help of "The Redesign Orbit", in its precise form as visualized and defined by Dumas et.al.[4]. Given its significance in regard of our experiments that will be presented later on (Ch.5), HPR was analyzed on a separate subsection. HPR holds a key role for the entirety of this thesis since the PAR heuristic that was selected in order to carry out the aforementioned experiments, is one of the best practices that are included in Heuristic Process Redesign and in particular belongs to the BP behavior subset. This chapter therefore serves as a proper starting point, by providing a thorough review of every known BPR method which in turn highlights their unique and fundamental traits in terms of their specific place within the "The Redesign Orbit" [4].

# 3. Key Concepts

In this chapter a concrete analysis will be conducted, regarding the entirety of the concepts that hold a prevailing role in our thesis. The establishment of a comprehensive background that will support our choices later on (Ch.4) for the creation of a desirable framework is critical. Our review begins with an overview of the Devil's Quadrangle and the 29 redesign heuristics [2], will continue to the model of Plasticity [3] and its related notions/model measures ,to eventually achieve its completion with a thorough assessment of the complexity model metrics and the threshold extraction mathematical methods.

## 3.1 Redesign Heuristics (Best Practices)

Since the beginning of the 1990s, best practices have been amassed and implemented in numerous areas such as healthcare, business planning and software development. Even though, a best practice defines ideally the most fitting solution to a specific problem that can be duplicated in any circumstance, a more productive way is to perceive it as something that "needs to be adapted in skillful ways in response to prevailing conditions" [2]. This chapter is dedicated to the analysis of analogous best practices aiming to strengthen the individuals responsible for the redesign of BPs and helping them overcome the main technical BPR challenge, which is the application of an upgraded process model. Their fundamental target is BPR endeavors, where the already existing BPs form the basis for their upcoming redesign. Which leads to the conclusion that when an appropriate best practice is implemented to a BP locally, directly results in the enhancement of the general efficiency [2]. As an opposing path we have the so-called clean sheet techniques, which involve designing an entirely new process from scratch. Although there is much debate in relevant literature regarding which of these two methods produces better results, having as a foundation a preexisting process is realistically the most ordinary technique to come up with a new process scheme. On most occasions the best practices that will be presented, were extracted from the experience obtained by monitoring large companies or consulting firms engaged in BPR [2]. As an illustration, the best practices proposed by Peppard and Rowland stemmed from the experience obtained while observing processes within the Toyota Motor Company [14]. According to Van Der Aalst the majority of best practices does not have quantitative support ,which is a noteworthy fact [15]. The subset of best practices that will be presented in this thesis is deemed universal in terms of application to the circumstances of any BP, and indifference to the services or products delivered. Some of the best practices we came across had to be excluded due to their limited scope of applicability, specific use for certain domains or even the fact that they had a more strategic approach. Therefore in order to classify the aforementioned subset, we need to pinpoint its main directions [2]:

- *Customers*: aiming to improve the relationship with clients.
- *Business process operation*: focuses on how the workflow is carried out.
- *Business process behavior*: its focal point being when the workflow is carried out.
- *Organization*: which takes into account the resources participating (types & number), as well as their distribution.
- *Information*: based on the information the BP uses, creates, may use or may create, it characterizes the best practices that are pertinent to these types of information.
- *Technology*: according to the technology the BP utilizes or may utilize in the future, outlines the best practices connected to that technology.
- *External Environment*: focuses on the improvement of the communication and association with third parties.

Product-oriented best practices were excluded from this classification, due to the fact that a redesign endeavor aims its attention at preexisting BPs and not at the product or service to be delivered. Furthermore this categorization does not show mutual exclusivity, meaning that some of the best practices are able to be assigned to more than one class [2]. Reijers and Liman Mansar believe that the product is strongly connected to the early scheme of the process on their previous paper, which outlines a formal technique for the production of a workflow by contemplating the product's structure. That technique is implemented to induce a new process design by relying on the clean-sheet approach [16].

## The Devil's Quadrangle

At this point in our literature review, the Devil's Quadrangle model will be introduced and discussed briefly. It has significant usefulness, especially, when any of the best practices presented in the following subchapter is applied in terms of improving a process by redesigning it. Its creators, Brand and Van der Kolk discerned four major aspects affected directly by a redesign effort: time, cost, quality and flexibility [2]. The main goals of a redesigned BP are to: decrease the time and costs necessary to manage and execute an order, enhance the quality of the services delivered and reform the capacity of the BP to adapt to diversity. The most interesting feature of their model is that by strengthening one aspect, opposite outcomes may be manifested on the others. As an illustration, additional settlement tasks could be included in a BP to enhance the quality of the services delivered, but this course of action may lead to impediments increasing the amount of time required for delivery [2]. As a result, in order to indicate these difficult compromises that sometimes are mandatory, Brand and Van Der Kolk refer to their model as the Devil's Quadrangle (Fig.5). Realization of the compromises that regulate a redesign measure, is a key factor in any redesign endeavor. In some occasions, the resulting redesign BP scheme may be considered worse than the preexisting, from specific viewpoints. Furthermore, applying several best practices combined may result in a partially negating effect on the respective desired changes, that each one of them aims to implement [2]. There are different operational ways for each one of the four dimensions illustrated in the Devil's Quadrangle. For instance, the aspect referring to cost includes several distinct types of cost and even more possible routes to focus on when pursuing to reduce operational costs. The attribution of a meaningful and precise translation to general concepts such as time, cost, quality and flexibility, heavily relies on the specific process context and needs to be taken into account. As a result the performance targets set upon by an organization towards a redesign effort, ideally should be defined as explicit applications of these four dimensions [2].

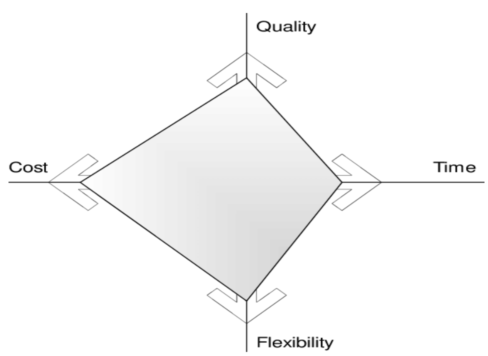

Figure 5: The Devil's Quadrangle [2]

## Overview & classification of the 29 Redesign Heuristics

In our analysis we will not evaluate the effectiveness of these heuristics on the four dimensions, in every conceivable way. Our attention will be aimed primarily at unambiguous understandings. As it was mentioned earlier, the classification of these practices will be performed according to the seven directions identified [2]: Customers, Business process operation, Business process behavior, Organization, Information, Technology and External Environment.

## Customers

### Control Relocation: “Move controls towards the customer”

The outline of this best practice is to move parts of a BP, such as checks and settlement tasks, towards the client. As an illustration Klein provides the case of Pacific Bell that transferred the billing controls towards its clients, eliminating the majority of billing errors, resulting in enhanced client satisfaction. A drawback of this technique is the higher probability of fraud, reducing income [2]. This best practice was named by Klein [17].

### Contact Reduction: “Reduce the number of contacts with customers and third parties”

Exchanging information with clients and/or third parties is time consuming, even more so when this exchange is conducted via regular mail. Significant wait times may be noticed, as well as the increasing possibility of intrusive errors with each additional contact. Hammer and Champy specify a case where a heavy compromise difficulty stems from the multitude of bills, invoices and receipts [2]. In terms of heightening quality and cutting down the BP’s throughput time, lowering the volume of contacts is the obvious solution. In fact, for specific information exchanges is not essential to avoid them entirely, but instead they can be incorporated with limited additional cost. Lowering the quantity of contacts might cause the loss of necessary data, introducing quality issues. On the other hand, integrating contacts may flood the delivery or receipt with too much data, which will affect directly the dimension of cost [2].Hammer and Champy [18] discussed this technique, while its quantitative analysis was conducted by Buzacott [19].

### Integration: “Consider the integration with a business process of the customer or a supplier”

The actual implementation of this best practice may assume distinct forms. Commonly, it can perceived as taking advantage of the supply-chain concept inside the domain of production [2]. As an illustration when two organizations reach an agreement upon collectively manufacturing a product, the more effective course of action is to carry out numerous transitional reviews rather than carrying out one large review once both organizations have completed their respective part. Taking into account cost and time dimensions, integrated BPs should provide more effective execution. The main disadvantage of this method is that over time the mutual dependency between the two organizations increases and , as a result, flexibility might decline [2]. The visual illustration of this best practice is shown in Fig.6.This best practice is mentioned by Klein [17] and Peppard and Rowland [14].

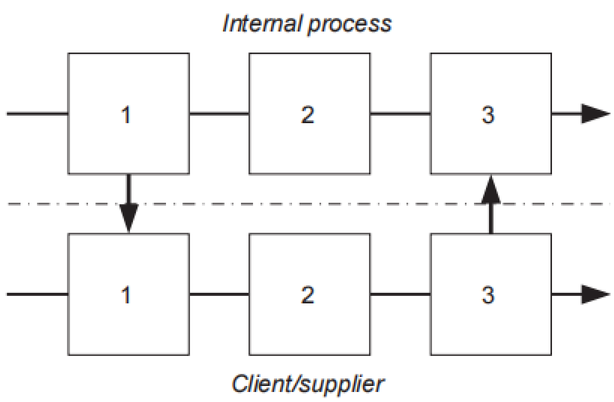


Figure 6: Integration [2]

## Evaluation

Concluding the analysis of client-oriented best practices, we will evaluate the effect each one of them has on the Devil's Quadrangle. The gray square stands for neutral effect on the four dimensions, while the effects of the other three best practices are highlighted by the other polygons. The positive or negative effects of a best practice on all dimensions can be deduced by comparing its polygon to the neutral effect square [2] (Fig.7).For instance, control relocation heuristic affects positively the quality dimension, negatively the cost dimension and has neutral effect on the time and flexibility aspects. Lastly, the illustrated outcomes are drawn on a relative scale [2].

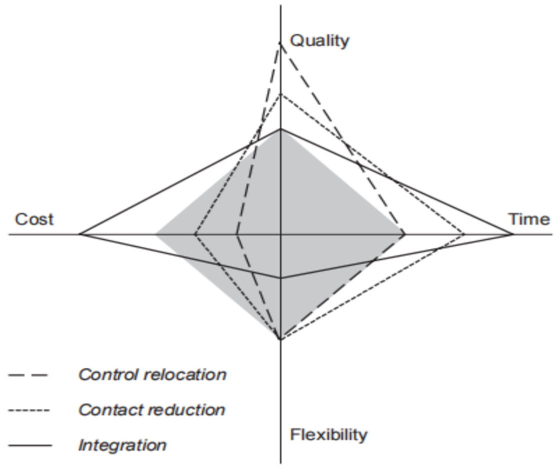


Figure 7: Evaluation of client-oriented best practices [2]

# Business Process Operation

## Order types: "Determine whether tasks are related to the same type of order and, if necessary, distinguish new business processes"

The basic outline of this heuristic is, identifying when a BP contains sub-flows of tasks that are not unique to the particular BP they belong to. By overlooking this circumstance, less adequate management of the aforementioned sub-flow may occur as well as a noticeable drop in its effectiveness. Implementing this heuristic might improve processing times and reduce costs [2]. Furthermore, identifying common sub-flows among many distinct BPs might result in the increase of performance. On the other hand, further coordination problems and fewer opportunities to redesign the BP in its entirety are possible drawbacks that may affect the quality and flexibility dimensions respectively [2].This best practice has been discussed in its various forms by Hammer and Champy [18], Rupp and Russell [20], Peppard and Rowland [14] and Berg and Pottjewijd [21].

## Task elimination: "Eliminate unnecessary tasks from a business process"

As a general rule, an accepted approach of deeming a task as not necessary is whether it adds any value from a client's perspective. A good example is control tasks, since they do not add value from customer's standpoint and their only purpose is to resolve problems that occurred in previous steps of the BP. On most occasions, repetition is the main identifying feature of control tasks. Therefore, task repetition can be perceived as a particular circumstance of task elimination [2] (Fig.8). Castano et. al., established a set of similarity coefficients which are entity-based, to assist with the effort of pinpointing superfluous tasks. These coefficients conduct automated checks on the degree of similarities among tasks and/or activities [22]. The primary goals of this best practice are, augmenting the processing speed and decreasing the costs necessary to manage an order. However, eliminating tasks might cause the quality of the delivered services to decline [2].This best practice appears frequently in literature, for instance, consult the particular papers of: Peppard and Rowland [14], Berg and Pottjewijd [21] and Van Der Aalst and Hee [23]. Buzacott [24] expressed the quantifiable effects of eliminating redundancies by utilizing a simplistic model.

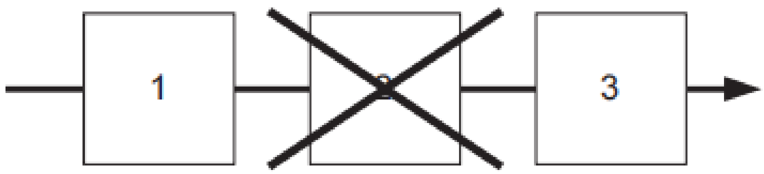


Figure 8: Task Elimination [2]

## Order-based work: "Consider removing batch-processing and periodic activities from a business process"

It is fairly easy to surmise that, there are some notable disruptions when a single order is handled: (1) being piled up in a bundle among other orders and (2) periodic activities, since processing relies heavily on computer systems which are not available at all times [2].By overcoming these obstacles ,the speed of handling singular orders may be increased substantially. Instead, by empowering batch order processing it is possible to achieve higher efficiency dictated by scale. Additionally, the cost required in order to make the necessary computer systems available at all times may be too steep [2].

## Triage: "Consider the division of a general task into two or more alternative tasks' or 'consider the integration of two or more alternative tasks into one general task"

Triage in its most prominent form, allows the possibility of creating new tasks that are better suited to the capacities of the available resources and/or the traits of the orders that need to be handled (Fig.9). Both cases lead to heightening the quality of the services delivered. Recognizing substitute tasks promotes as well a better employment of the available resources, with positive outcomes on the time and cost dimensions [2]. Although, having too much specialization can have a negative impact on the flexibility dimension of a process, its efficiency and quality due to the fact that it causes tiresome and repetitive work. An alternative scheme of the triage heuristic can be considered, by dividing tasks into similar instead of substitute ones for the different types of orders being handled. It is noteworthy that this best practice shares many similarities with the order types heuristic, when the first is viewed as the fundamental interpretation of the second on a task level. The notion of triage is discussed by Klein [17], Berg and Pottjewijd [21] and Van der Aalst and Van Hee[23]. Zapf and Heinzl [25] indicated the positive impact of triage in the environment of a call center ,while Dewan et.al. [26] examined the effects of triage on organizations in regard to the reduction of cycle-time.

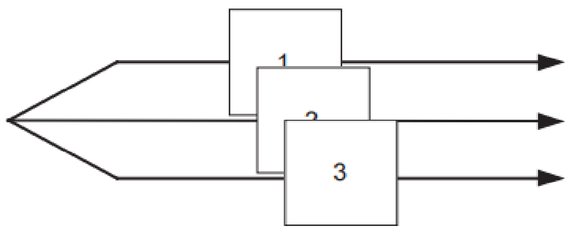


Figure 9: Triage Best Practice [2]

## Task composition: "Combine small tasks into composite tasks and divide large tasks into workable smaller tasks"

In order to comprehend this best practice better, the definition of "setup times" needs to be provided. Specifically, the term "setup times" stands for the amount of time spent by a resource in order to familiarize itself with the details of an order. Therefore, when tasks are combined setup times should be decreased and executing the new larger tasks ,which are the aforementioned combination of several smaller ones, may elevate slightly the quality of the delivered services [2]. However, making tasks too large may have a negative impact on:(a) the flexibility due to longer run-times and (b) the quality, since having larger tasks deems them as less workable. To counterbalance these outcomes the obvious solution is to divide large tasks into smaller ones, eventually giving up smaller setup times in the process (Fig.10) [2].

Probably the practice with the most citations, mentioned by Hammer and Champy [18], Rupp and Russell [20], Peppard and Rowland [14], Berg and Pottjewijd [21], Seidmann and Sundarajan [27], Reijers and Goverde [28], Van der Aalst [29] and Van der Aalst and Van Hee [23]. Some of these authors considered only one aspect of this practice, i.e., the combination of smaller tasks into larger.

However, Buzacott [24], Seidmann and Sundarajan [27] and Van der Aalst [29] also provided measurable support for the optimization of simple models.


Figure 10: Task Composition [2]

## Evaluation

Having concluded our analysis on the business-process-operation oriented best practices, our evaluation will be presented in a similar manner to customer-directed heuristics (Figs.11, 12).

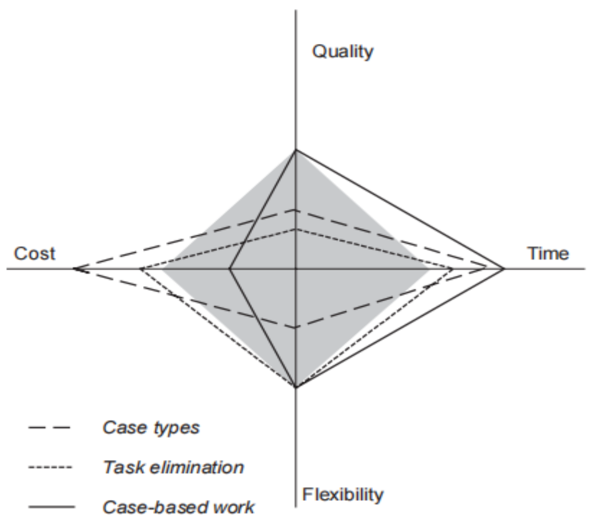


Figure 11: Evaluation of business process operation best practices (a) [2]

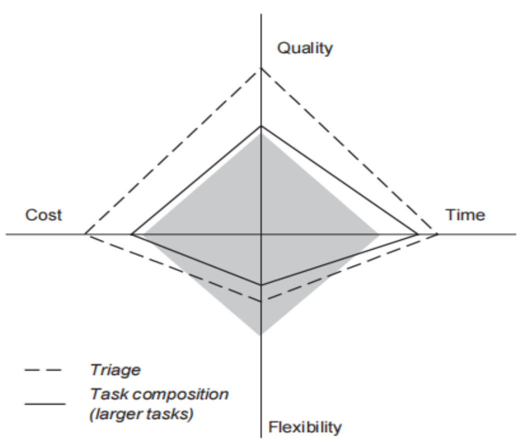


Figure 12: Evaluation of business process operation best practices (b) [2]

# Business Process Behavior

## Resequencing: "Move tasks to more appropriate places"

The exact sequence of tasks and their interdependencies is not evident in current BPs (Fig. 13). Quite often it is preferable to postpone a task's execution if it is not a prerequisite to the following tasks, in order to determine whether its execution is redundant [2]. By not executing superfluous tasks, operational costs are decreased. Additionally, tasks may be moved across the BP according to the similarities they have, minimizing setup times [2].

In this particular form, this practice is discussed by Klein [17]. "Process order optimization" is an alternative term used for this redesign heuristic.

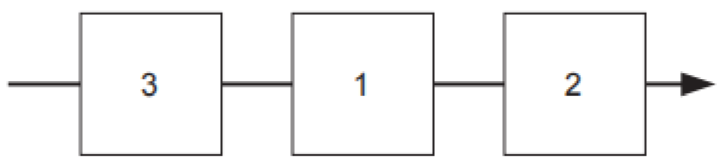


Figure 13: Resequencing [2]

## Knock-out: "Order knock-outs in an increasing order of effort and in a decreasing order of termination probability"

Checking various criteria that need to be met before delivering a satisfactory end result, is a common procedure of BPs. A knock-out event causes immediate termination of a specific part of a BP, when the required conditions for its execution are not satisfied (Fig.14) [2]. When it comes to selecting the order of checking these conditions and no specific constraints need to be fulfilled regarding that order, the condition that possesses the most favorable ratio of anticipated knock-out expectation divided by the required effort to verify the condition should be pursued first. In this manner the second check is performed on the condition with the second-best ratio, until all checks are complete [2]. Adapting this system of check arranging offers on average the most efficient BP execution in terms of cost. Despite the fact that this best practice does not have any obvious deficiencies, in many occasions it may not be possible to organize these checks without any hindrances. Also, by putting this best practice into action may cause longer throughput times, when compared to an entirely parallel checking of the conditions needed to proceed. Essentially, it is a specific form of the resequencing heuristic [2].

Van der Aalst mentions this best practice and also provides quantitative support for the optimization of simple models [29].

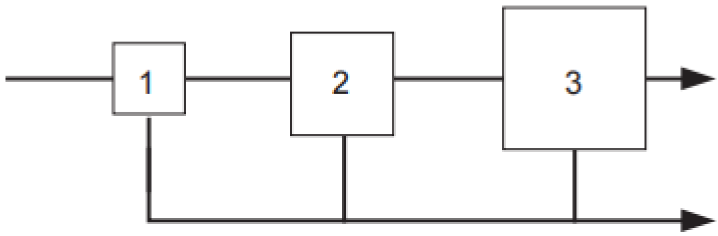


Figure 14: Knock Out [2]

## Parallelism: "Consider whether tasks may be executed in parallel"

When executing tasks simultaneously, i.e., putting them in parallel, BP throughput times may be greatly reduced (Fig.15). Parallelism has a wide area of applicability in the domain of BPR. In the majority of existing BPs, tasks are arranged sequentially lacking any evidence of hard logical restrictions that could possibly dictate such an order [2].By inserting more parallelism to a BP that combines probabilities of knock-out events, the costs of execution may become larger which a substantial disadvantage of this best practice[2]. Furthermore, managing BPs with simultaneous behavior can have increased complexity introducing errors and/or restrictions regarding their quality and flexibility respectively. At its core, Parallelism is also a unique form of the resequencing heuristic [2].

It is mentioned by Rupp and Russell [20], Buzacott[24] , Berg and Pottjewijd [21] and Van der Aalst and Van Hee [23] . Van der Aalst [29] provides quantitative support as well for this best practice.

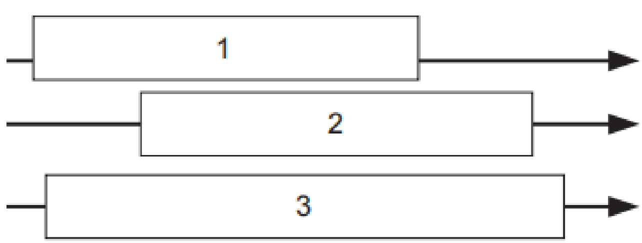


Figure 15: Parallelism [2]

## Exception: "Design business processes for typical orders and isolate exceptional orders from normal flow"

Special case orders may cause disruptions on the normal flow of operations. Specifically, it requires workers to familiarize themselves with the details of that special case order even though they might not have the ability of handling it successfully, increasing significantly its setup time [2]. Therefore, by isolating exceptional orders, e.g., applying triage heuristic, the management of normal orders will become more economical. Isolating these exceptions may also have a direct positive impact on the overall efficiency, since particular expertise can be accumulated by workers handling these special case orders. Employing this best practice will cause the BP to have increased complexity and quite possibly reduced flexibility [2]. Additionally, this best practice predicates that if the required knowledge to manage this exceptions has not been obtained yet, no significant improvements will occur [2]. Poyssick and Hannaford [30] and Hammer and Champy [18] discussed this redesign best practice.

## Evaluation

The evaluation of business process behavior directed heuristics is presented in the following scheme (Fig.16).

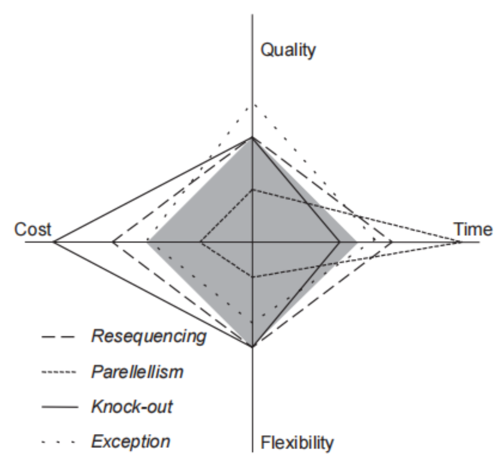


Figure 16: Evaluation of Business Process Behavior best practices [2]

# Organization – Structural perspective

## Order assignment: "Let workers perform as many steps as possible for single orders"

Employing order assignment (Fig.17) in its most absolute form, the resource carrying out its respective tasks is chosen from a list that are able to perform it and already has previous similar order experience. Additionally, a notable benefit of this best practice is that the persons chosen to execute specific tasks will eventually familiarize themselves with the cases at hand, resulting in smaller setup times and increased quality [2]. On the other hand, the allotment of resources becomes less flexible and the completion of an order may suffer from increased queue time ,if the assigned resource is unavailable at the time [2].This particular redesign method is mentioned by Rupp and Russell [20], Hammer and Champy [18], Reijers and Goverde [28] and Van der Aalst and Van Hee[23].

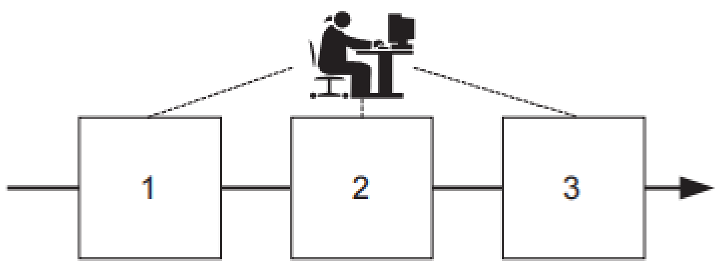


Figure 17: Order Assignment [2]

## Flexible assignment: "Assign resources in such a way that maximal flexibility is preserved for the near future"

As an illustration, when a task can be carried out by two resources it should be assigned to the most specialized one. In this manner, the possibilities to have the more general resources executing another task available, are optimum [2]. On the positive side, queue times are decreased: there is a smaller probability that an order has to wait for specific resources to become available in order to be completed. Moreover, workers with the highest levels of specialization are expected to handle most of the work, thus improving the quality. On the negative side, this redesign method has various drawbacks. Decreased job satisfaction may occur due to the possible unbalanced work load and the chances for specialists evolving into generalists become smaller [2].This best practice is mentioned by Van der Aalst and Van Hee [23].

## Centralization: "Treat geographically dispersed resources as if they are centralized"

A Workflow Management System (WfMS) exhibits several utilization advantages and this redesign heuristic is specifically tailored to capitalize on them [31]. When such a system assigns work to resources, the dependency on their geographic location is irrelevant. Which leads us to the conclusion, that this best practice is a particular method of the integral technology heuristic [2]. The distribution of resources is more flexible, resulting in better usage and perhaps smaller throughput amounts of time. However, its drawbacks are analogous to these of the integral technology best practice [2].This best practice is mentioned by Van der Aalst and Van Hee [23].

## Split responsibilities: "Avoid assignment of task responsibilities to people from different functional units"

Shared responsibilities among different departments for specific tasks might lead to disputes and negligence within an organization. In order to improve upon the quality of task completion, overlapping in responsibilities needs to be decreased (Fig.18) [2]. This may lead to elevated receptivity regarding the available work, positively affecting service times. The downside is that by having less resources available for work , throughput times may be increased as a result of longer queue periods [2].Rupp and Russell [20] and Berg and Pottjewijd [21] , have discussed this best practice.

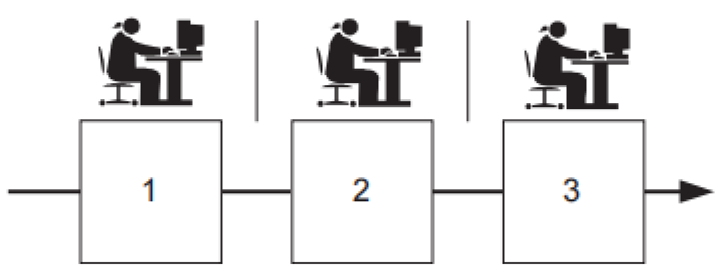


Figure 18: Split responsibilities [2]

## Customer teams: "Consider assigning teams out of different departmental workers that will take care of the complete handling of specific sorts of orders"

This heuristic derived from the order assignment best practice. The application of this redesign technique may be motivated by order assignment, based on its precise desired form. A customer team may have more persons with similar expertise working together, requiring less specialists than order assignment to complete tasks [2]. Benefits and drawbacks are analogous to these of the order assignment best practice. Furthermore, teamwork may enhance several sub-dimensions of the quality aspect such as, attractiveness of the work and create a better overall insight [2].Peppard and Rowland [14], Hammer and Champy [18] and Berg and Pottjewijd [21] have examined this best practice.

## Numerical involvement: "Minimize the number of departments, groups and persons involved in a business process"

The implementation of this redesign method aims to reduce coordination problems, making more time available for the management of orders[2]. Lowering the number of departments may contribute to less split responsibilities, with comparable positive and negative effects as the split responsibilities best practice has, that was mentioned earlier. Having less specialized resources may prevent the accumulation of expertise and routine [2]. This best practice is shown on Fig.19.Rupp and Russell [20], Hammer and Champy [18] and Berg and Pottjewijd [21] have discussed this best practice.

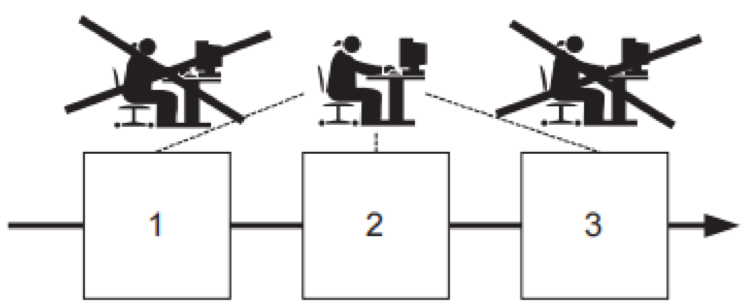


Figure 19: Numerical Involvement [2]

## Case manager: "Appoint one person as responsible for the handling of each type of order, the case manager"

Specific clients and/or cases constitute the domain of responsibilities for a case manager, although he or she will not be the sole resource allocated to handle these. Compared to the order assignment heuristic, evidently concludes that the emphasis from the execution of the process has shifted to its management [2]. The improvement of a BP's external quality is the capital purpose of this best practice, enhancing its transparency from a client's perspective due to the fact that a case manager represents a single point of contact. In turn, this results in increased customer satisfaction [2]. Furthermore, internal BP quality may be positively affected, given the fact that the appointed case managers are accountable for correcting any mistakes that may occur. The obvious drawback of applying this best practice is, the increased cost of appointing case managers since it requires increased capabilities in order for them to work on the orders successfully [2]. Van der Aalst and Van Hee[23] and Hammer and Champy[18] have analyzed this best practice, while Buzacott [24] provided as well partial quantitative support for particular interpretations.

## Evaluation

The assessment of the heuristics that are directed towards an organization's structural point of view are depicted in Figs. 20, 21.

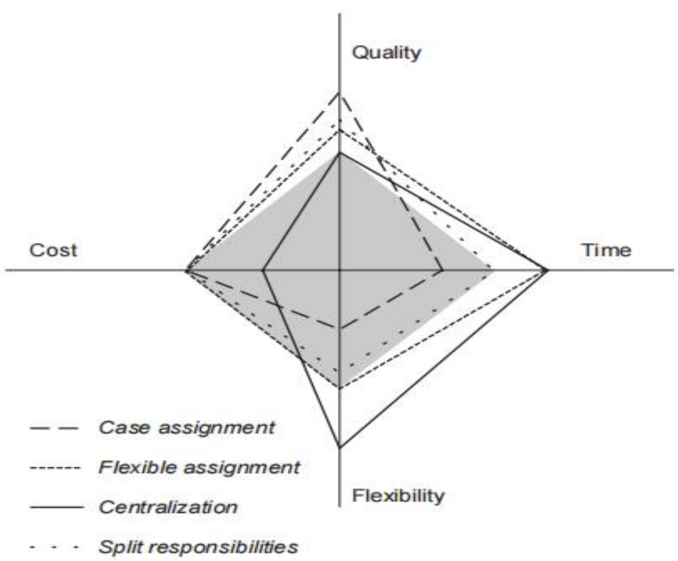


Figure 20: Evaluation of organizational structure best practices (a) [2]

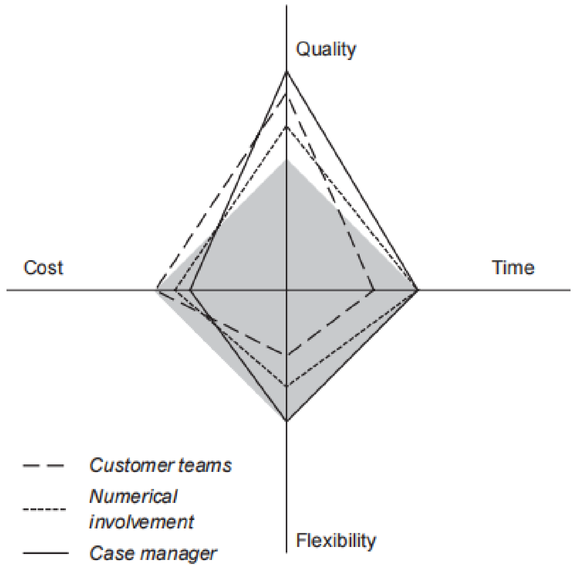

Figure 21: Evaluation of organizational structure best practices (b) [2]

# Organization – Population perspective

## Extra resources: "If capacity is not sufficient, consider increasing the number of resources"

This best practice is self-explanatory (Fig.22). The apparent advantages of utilizing this heuristic are, more available resources to handle orders therefore decreasing queue times and quite possibly leading to a more flexible resource allocation scheme [2].On the negative side, buying or hiring additional resources comes with an elevated cost. This redesign method antagonizes directly the numerical involvement best practice [2]. Berg and Pottjewijd [21] discussed this redesign heuristic. Van Hee et. al. [32] addressed different strategies regarding the optimal distribution of additional resources in BPs.

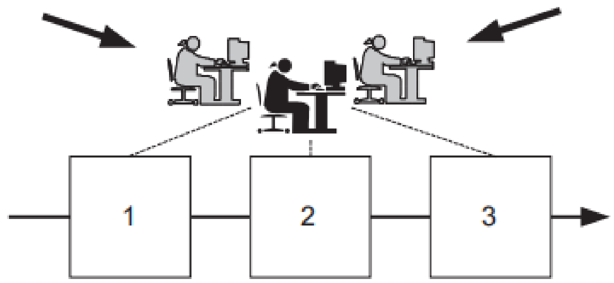


Figure 22: Extra Resources [2]

## Specialist-generalist: "Consider to make resources more specialized or more generalist"

Depending on the organization's needs, generalists can be converted to specialists and/or vice versa (Fig.23). Whilst a specialist resource can expand his or hers expertise through training, a generalist after having been allocated to a specific type of work for long periods of time, may cause his other capabilities to become outdated [2]. When the redesign endeavor of a BP is under debate, applying this heuristic essentially comes down to considering the generalist-specialist ratio of the resources to be hired. Routine tasks are handled faster by specialists and they may also possess more extensive knowledge than generalists do [2]. This results directly in higher quality of delivered services and smaller task completion times. However, by having generalists available leads to increased BP flexibility and possibly a better distribution of resources. Judging by the degree of generalization or specialization, either form of resources may have elevated costs [2].Grover et.al.[33] and Berg and Pottjewijd[21] express the advantages of having specialists. While Rupp and Russell [20] and Seidmann and Sundarajan [27] mention specialists and generalists.

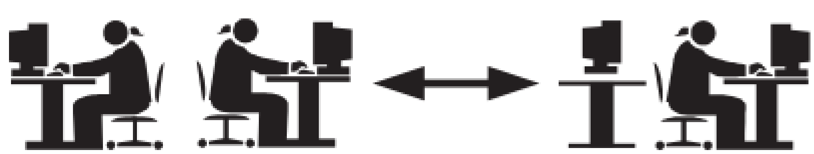

Figure 23: Specialist-generalist best practice [2]

## Empower: "Give workers most of the decision-making authority and reduce middle management"

Validating work done by others is a common course of action in conventional BPs, that requires significant amounts of time. Therefore, lower throughput times and smoother conduct of business may be the results of empowering workers to decide independently in terms of order handling (Fig.24). By reducing middle management spots within a BP, also lowers the labor costs necessary to process the orders [2]. Potential disadvantages may be, that the quality of decisions is declining and that the occurrence of obvious errors during the execution of the BP is not dealt with properly. In the cases of errors or bad decisions forcing the rework of an order, handling costs may actually be elevated when compared to the original state of conducting business with less empowerment [2].Hammer and Champy [18], Rupp and Russell [20], Seidmann and Sundarajan[27] and Poyssick and Hannaford[33] addressed this best practice. Buzacott [24] illustrated how with a simple model ,performance may be augmented by employing this redesign heuristic.

Figure 24: Empower best practice [2]

## Evaluation

The evaluation of the heuristics aimed at the population of an organization are shown in Fig.25. Also in the aforementioned scheme, regarding the specialist-generalist best practice only the analysis of more specialists is included[2].

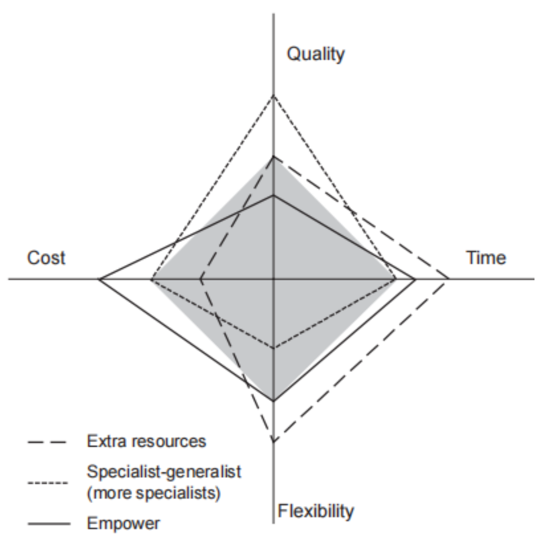


Figure 25: Assessment of the organizational population best practice [2]

# Information

## Control addition: "Check the completeness and correctness of incoming materials and check the output before it is sent to customers"

As its title states, this best practice advocates the inclusion of controls to a BP. Potentially it might motivate a higher quality of the BP execution, which contributes to less necessary rework of orders (Fig.26) [2]. As a consequence, introducing additional controls to a BP demands more time and allocated resources. Additionally, it is worthy to mention the contradiction between the intent of this heuristic and that of task elimination, which is a business process operation oriented best practice [2].Poyssick and Hannaford [33], Hammer and Champy [18] and Buzacott [24] addressed this redesign best practice.

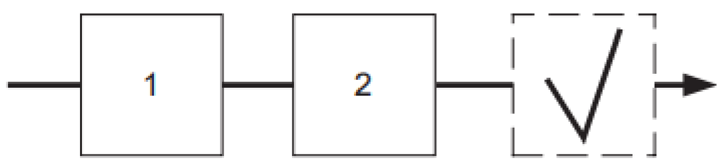


Figure 26: Control Addition [2]

## Buffering: "Instead of requesting information from an external source, buffer it by subscribing to updates"

The action of acquiring necessary information from third parties consumes significant amounts of time in many BPs (Fig.27). Throughput times may become greatly smaller, when the necessary information is directly available. This method comes into immediate comparison with the caching principle that microprocessors employ [2]. However, subscribing to information updates comes with an increased cost, especially when considering sources that enclose far more information than is ever used on a regular basis. Additional costs may also be introduced by saving and maintaining all this information. This best practice is a weak variation of the integration heuristic. In the case of buffering a copy is maintained, instead of direct access to the original information which would be granted through the integration with a third party [2].

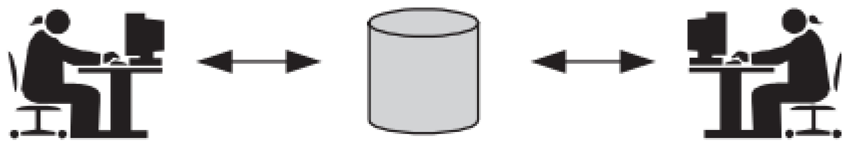

Figure 27: Buffering [2]

## Evaluation

The effects of information best practices on the Devil's Quadrangle are synopsized in Fig.28.

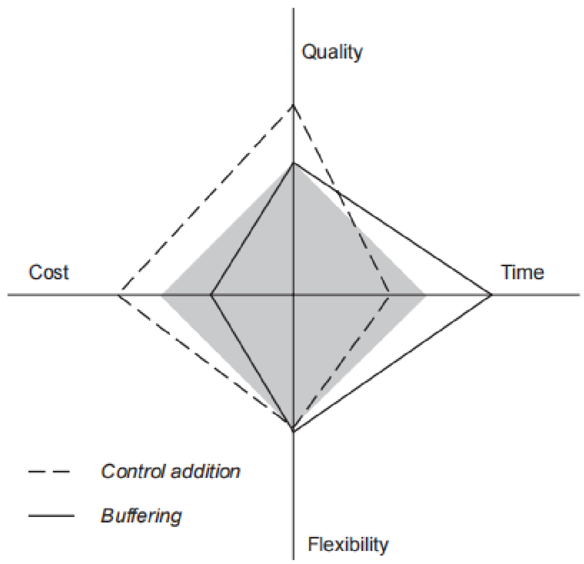


Figure 28: Assessment of information best practices [2]

# Technology

## Task automation: "Consider automating tasks"

When automated tasks are implemented to a BP, the execution of tasks becomes faster with smaller costs and enhanced overall quality. Although, the advancement of an automated task performing system may be proven as significantly expensive [2]. In general, a human resource exhibits more flexibility when it comes to handling variations than an automated system. Therefore, the automated support of task-performing resources should be taken into consideration, instead of complete task computerization[2]. The business process angle of e-commerce is an eye-catching application of this best practice: defined by Kalakota and Whinston[29] and cited by Gunasekaran et.al.[30], as the implementation of technology towards automated business workflows and transactions. Peppard and Rowland [14], Hammer and Champy [18] and Berg and Pottjewijd [21] addressed this redesign technique.

## Integral technology: "Try to elevate physical constraints in a business process by applying new technology"

New technologies have the capacity to bring a variety of positive impacts on BPs. As an illustration, applying a WfMS may lead to smaller amounts of time spent on completing logistical tasks [2]. Document Management Systems will make all the available information related to orders immediately accessible to all participants, enhancing in this manner the quality of delivered services. New technologies can also revolutionize the conventional approach of conducting business by granting entirely new possibilities to all the participants [2]. The endeavors related to technology, such as the purchase, application, advancement, maintenance and training of the workforce are straightforward cost-elevating factors. Furthermore, new technologies may incite fear within the workforce or other subjective matters, that potentially may lower the BP quality altogether [2].This particular redesign best practice was discussed by Klein [17], Peppard and Rowland [14], Berg and Pottjewijd [21] and Van der Aalst and Van Hee[23].

## Evaluation

The discussed impacts of the information-directed best practices are shown in Fig. 29. In order to better comprehend the various outcomes of the integral technology heuristic, the effects of a WfMS are depicted as a reference.

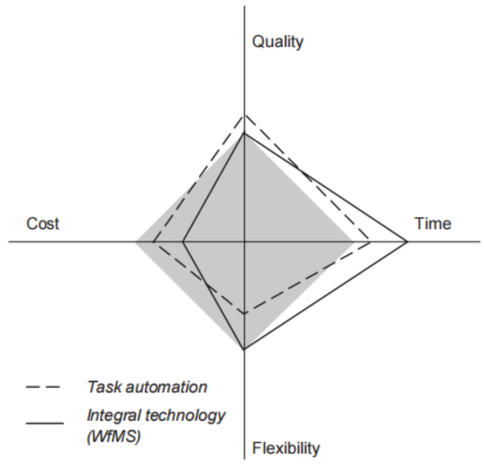


Figure 29: Evaluation of technology best practices [2]

# External Environment

## Trusted party: "Instead of determining information oneself, use results of a trusted party"

In several cases, some of the assessments and resolutions reached within the context of a BP, are not specifically made for the BP they belong to. There is a possibility that third parties may already have concluded on the same pieces of information, that could replace the previous resolutions or assessments[2]. A fitting example is when a bank (bank 1) wants to authenticate the creditworthiness of a client. If the client presents documents that prove his creditworthiness from a different bank (bank 2), then bank 1 will accept them. Employing this best practice, affects positively the dimensions of cost and time. On the negative side, the BP quality relies on some of the third party's work and additional endeavors in terms of coordination with the trusted parties might be required, which causes flexibility to decline [2]. Lastly, this heuristic differs from the buffering best practice, due to the fact that the owner of the BP, is not the person obtaining the information [2].

## Outsourcing: "Consider outsourcing a business process in whole or parts of it"

High efficiency when performing tasks of a BP is a key factor. Therefore, in terms of handling the same type of work, other parties may be more efficient regarding the time and cost dimensions. In that case, an organization may choose the party that fits best their goals to handle their work, by outsourcing it [2]. The main advantage of utilizing this best practice, is to minimize the generated cost. However, outsourcing requires additional coordinated efforts that cause the complexity of the BP to increase. Furthermore, a potential disadvantage may be the decreased overall quality [2]. There is a distinct difference between this best practice and that of the trusted party. When outsourcing tasks of a BP, they are executed at run time by the selected party. Whereas the trusted party best practice allows the use of recent results, i.e., certificates and documents [2].Klein [17], Hammer and Champy [18] and Poyssick and Hannaford [33] mentioned this best practice.

### Interfacing: "Consider a standardized interface with customers and partners"

The fundamental intention behind this heuristic is, that by establishing a regulated interface will eliminate the possibility of errors, partially complete applications, incomprehensible communications, etc.[2]. Less errors, faster processing times and decreased reworking of orders, may be some of the potential advantages when applying this best practice. It can be viewed as a particular embodiment of the integration best practice, even though it is not aimed directly towards clients [2].Poyssick and Hannaford [33] and Hammer and Champy [18] discussed in depth this redesign method.

## Evaluation

Concluding our analysis on the external environment best practices, their effects on the Devil's Quadrangle are presented in Fig.30.

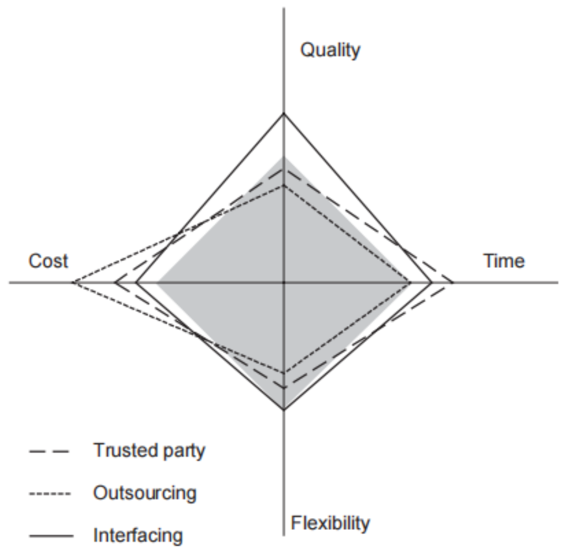


Figure 30: Evaluation of external environment best practices [2]

# 3.2 Plasticity, Related Concepts & BP Model Measures

In this chapter of our thesis, the various perceptible concepts relevant to Plasticity will be reviewed. Furthermore, an in-depth analysis of the distinct BP model measures and related concepts, regarding both of the external and internal BP quality areas will follow.

## External & Internal Quality of BP Models

Before delving into the analysis of plasticity and its related concepts, we need to address the areas of internal and external model quality. This examination will greatly improve the overall apprehension of the following subchapters.

## External BP Model Quality

External BP model quality is directly related to the impression it leaves on users. By measuring it the model in question is viewed as a black box, while the properties that are relevant to the impact on clients are addressed [36]. In regard to the general quality of models, external quality represents the most questionable area due to the lack of an agreement within the research community. Therefore, the quality characteristics were selected from international standards and relevant proposals, using as a selection precedent the idea of embracing software quality aspects in the domain of BP models [36]. These quality traits can be viewed in Fig.31.

The characteristics presented in Fig.31 seek to provide an accepted definition for the external BP model quality term. The categorization illustrated in Fig.31, represents the most frequently agreed on ,arrangement of external BP quality traits, inside the research community and international standards [36]. The SLR (Systematic Literature Review) conducted by Gonzalez et.al. revealed that the majority of these attributes were adopted either from the ISO 9126 [37] or its successor which is the ISO 25010 [36],[38]. Although some of them appeared only in proposals, they were selected due to the fact that the same SLR showed that most of the authors recognized their relevance to the domain of external BP quality [36].

| Characteristic/ Sub-characteristic | Definition |
|---|---|
| **Usability:** Degree to which a model can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use | |
| Understandability | Attributes of models that have a bearing on the users' effort to recognize the logical concept and its applicability |
| Learnability | Degree to which a model can be used by specified users to achieve specified goals when learning to use it |
| User interface aesthetics | Degree to which the model provides the user with a pleasing and satisfying interaction |
| **Maintainability:** Degree of effectiveness and efficiency with which a model can be modified by the intended maintainers | |
| Modularity | Degree to which a BP design is composed of discrete models, such that a change to one model has a minimal impact on another |
| Modifiability | Degree to which a model can be effectively and efficiently modified without introducing defects or degrading existing product quality |
| **Adaptability:** Degree of effectiveness and efficiency with which a model can be adapted from one notation to another | |
| **Correctness:** Degree to which a model does not have workflow errors or faults, such as deadlocks | |
| **Completeness:** Degree to which a model has all the necessary, relevant information | |
| **Consistency:** Degree to which a process and the subprocesses in a model have no contradictions, together with the labels, the data across activities, and the requirements document of the model | |

Figure 31: External Quality Characteristics [23]

## Internal BP Model Quality

The evaluation of structural traits of the process models, as well as other non-structural attributes such as the appropriate labeling of activities [39],is what constitutes the domain of internal BP model quality [36]. In this case, the process model is viewed as a white box where all of its static properties, that are commonly available for evaluation during its design stage, are addressed. The outcome of the design stage of a BP model, is a theoretical model which exhibits quantifiable-by-measures features. As an illustration, the control-flow complexity measure (CFC)[7] highlights the structural complexity of a model in relevance to its gateways, proclaiming that it contributes to the information regarding its internal quality [36]. Attempting to determine the internal quality of models, relies solely on the idea of applying a selection of measures (number of nodes, connector heterogeneity, etc.) which in turn provide the required information about them and support their quality (or the lack of it)[36].

## The impact of internal quality on external quality

To prove the correlation between measures and external quality characteristics, the Software Measurement Ontology (SMO) [40] is the best course of action. The ontology was defined in such a way that is capable of representing the entirety of the elements involved in the measurement process: "A quality model evaluates measurable concepts, which are related to attributes. Measurement is performed on attributes and entities. Measures are defined for attributes" [36], [40]. Therefore, this rationale explains the need of correlating measures to external quality characteristics in an endeavor to determine which measures are the most appropriate for carrying out the evaluation of a theoretical model's general quality [36]. The relationship between external quality and internal quality is depicted in Fig.32, which provides a clearer explanation.

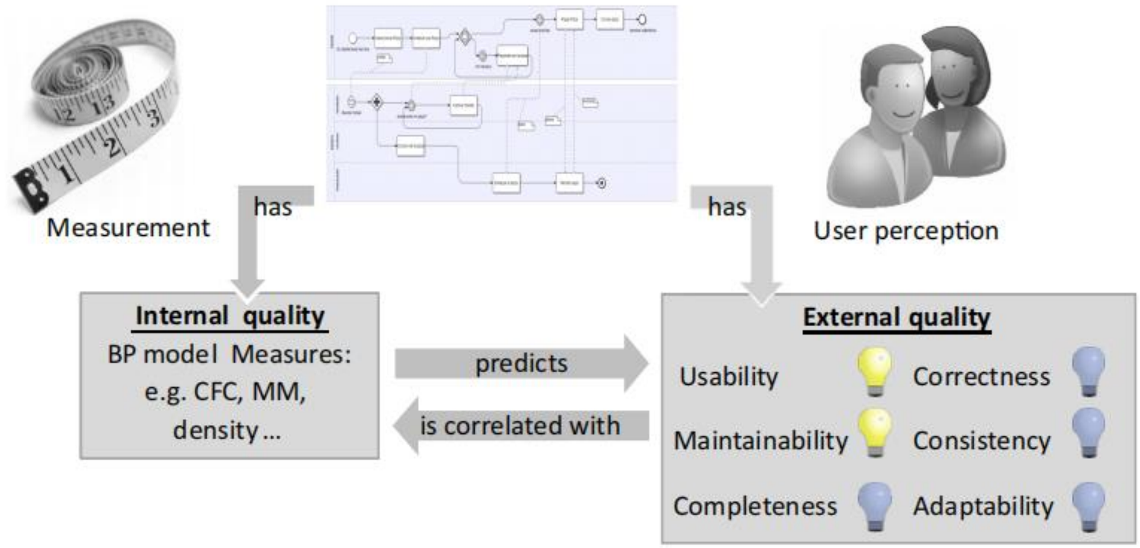


Figure 32: The relationship between external & internal BP model quality [23]

The process begins with the application of measures on BP models in order to create the required measurement information. Supposedly these models have no syntactic errors, but their overall level of quality remains unknown at this stage [36]. Given the fact that the link between external quality characteristic and internal model measures was established through correlation analysis, the previously obtained measurement information is used to forecast the levels of all the quality aspects [36]. Namely, each quality trait can be calculated by applying a selection of internal quality model measures, and it is considered to be on a satisfactory level when the measures applied do not surpass specific thresholds [36]. If one of the light bulbs lights up, it means that the measures applied are signifying that a particular characteristic has not reached the acceptable level. Obviously, the light bulbs are a metaphor that "light up" when a trait has not attained the desired standard, activating that particular trigger. In that case, some of the redesign practices should be applied to the model in question. When the redesign effort is complete, the model can be once again a viable candidate for further improvement [36].

## Plasticity

Tsakalidis et.al.[3], introduced an original BP model measure, that draws its inspiration from brain plasticity (Neuroplasticity). In accordance with Mariano et.al. [41], Neuroplasticity is the capability of a nervous system to adapt at fundamental and functional levels along neural advancement and, when exposed to new ideas, the performance of distinct departments is augmented. In a similar manner, BP model plasticity is established as the capacity of a process model to be remodeled in response to extrinsic or intrinsic stimuli, by rearranging its structure (activities, connections, functions) [3]. The term intrinsic stimuli, is directly related to the intra-organizational feedback deriving from measurements, process analysis, etc. On the other hand, extrinsic stimuli expresses the clients' feedback on BP redesign endeavors in terms of producing better products and/or delivering higher quality of services [3]. The concept of plasticity is fundamentally distinct when compared to analogous BP notions, such as agility and flexibility. Instead of focusing on the model's capacity to change at runtime, plasticity indicates the potential of models to be redesigned which precedes the implementation-of-redesign-efforts phase [3].

## Concepts Related to Plasticity

Following our brief analysis on the definition of the plasticity notion, in this subsection we shall discuss the differences between plasticity and its relevant measurable concepts. Two of the external quality measures embraced by the BP quality sphere, that originally belonged to the ISO standards on software engineering product quality realm, are modifiability and changeability [3]. These concepts are both parts of the maintainability one which is more general, while the more inclusive term of modifiability is a product that resulted by associating the changeability and stability notions together. ISO/IEC 25010:2011 defined modifiability as, "the degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading existing product quality"[38]. Similarly, changeability was characterized in the removed standard ISO/IEC 9126-1:2001 as, "the capability of the software product to enable a specified modification to be implemented"[37]. When it comes to acclimating towards the extended changes required to meet the end user stipulations, both of these notions have been pivotal gauges regarding this specific capability of BP models. However, they are more generic in terms of defining a model and its capacity to be modified, while plasticity's central focus is on the appropriateness of distinct redesign best practices [3].

## BP Agility

Agility represents one of the two most relevant concepts to plasticity, within the domain of BPs. Chen et al. [42], characterized the notion of BP agility as the lack of difficulties (to a degree) and speed at which organizations can remodel their BPs in order to avoid dangers in their corresponding markets. Equivalently, Tallon[43] delineated BP agility as an outside-in ability which indicates the way that organizations act on changes, by developing how their business activities are carried out. The obvious conclusion, after having compared these two definitions, is that BP agility focuses mainly on the versatility and impartiality of organizations to either adjust their business activities to the needs of their clients or respond to market threats [3]. Therefore, it is a fundamentally dissimilar concept to plasticity, since 1) it focuses on the BP's capacity to be altered during its runtime, while plasticity focuses on the models' capacity to be redesigned before any redesign effort is applied, and 2) BP agility is an outside-in model ability while plasticity also contains intrinsic stimuli (i.e., measurement, intra-organizational feedback established by business analysis, etc.), but includes extrinsic stimuli as well [3].

## BP Flexibility

Van Eijndhoven et. al. [44] alleged that BP flexibility is amply mentioned in the existing literature. However, there are significant difficulties in order to signify its definition, even with the use of well-established and quantitative terms [3]. Schonenberg et.al. [45], characterized BP flexibility as the capability to handle both foreseen and unforeseen changes, by remodeling the BP parts affected by said changes while retaining the parts that were not affected. In [46], Schonenberg et.al. introduced four separate types of process flexibility: flexibility by design, flexibility by deviation, flexibility by underspecification and flexibility by change. More importantly, the distinct types of flexibility indicate that most of them substantially differ from the concept of plasticity, as they refer to managing expected changes or infrequent unanticipated performance within the operational setting [3]. Flexibility by change mainly mirrors plasticity which illustrates either dealing with infrequent and unanticipated performance, where changes require process alterations or adaptations, or managing perpetual unexpected performance [3].

## Process Modification Flexibility

Process modification flexibility represents another analogous notion to plasticity, that was defined in [47] as "the capacity to alter the process (no. of sub-flows in the workflow, complexity, quantity of outsourced tasks, etc.)" [3]. Considering that it signifies the capability of models to be altered in a more characteristic manner that entails employing redesign practices, process modification flexibility is a proportionate concept to plasticity [3]. However, unlike plasticity, it lacks discernment that subjects to the category of modification. Additionally, process modification flexibility still is an uncharted notion and its quantitative assessment does not exist in current literature [3].

## BP Model Measures

Quantifiable BP model concepts such as quality, complexity, entropy and density are indicated by the internal measures of BP models. These measures represent crucial gauges, that are directly linked to the above-mentioned measurable BP model concepts [3].Among these notions complexity is the most perceptible, since it appears quite often in the existing literature where various interpretations exist [10]. In this thesis, our main focus is set upon the complexity notion, given the fact that we aim to deduce the correlation between the complexity of BP models and the plasticity concept. Cardoso [7] ,defined it as : " the degree to which a system or component has a design or implementation that is difficult to analyze, understand or explain". Mendling stated that complexity cannot be assessed by utilizing only a specific type of measures, which led to the creation of sixty-six different BP model complexity metrics [8],[9],[10]. Although, many proposals include simple metrics such as Depth and Number of Activities, Joints and Splits (NoAJS) that are fairly easy to calculate, these do not embody the heterogeneity of structural components that are part of the BP model in question. In opposition, measures like Connectivity Level between Activities (CLA) or Coefficient of Network Complexity (CNC) recognize any variations regarding the structure of a BP model, but attempting to calculate or to understand them may eventually be proven more difficult than anticipated, from a designer's standpoint [3].In the following chapter of our analysis, these complexity metrics will be reviewed in order to provide a better understanding of the complexity BP model concept.

# 3.3 Complexity Metrics

Prior to proceeding with the presentation of the sixty-six distinct complexity measures, it is necessary to familiarize ourselves with all the terms, notions and methodologies related to the complexity of process models. We shall begin our analysis by defining some fundamental terms such as, model, diagram and notation, gradually reaching and eventually presenting the complexity metrics.

## BP models, diagrams and notations

A BP model can be interpreted as a precise depiction of either a real ("AS IS") or a proposed ("TO BE") BP, that justifies the order of its events and activities, along with all the pertinent consistencies that exist between them [10]. Therefore, this model is a direct outcome of modeling activities, which intends to enhance, advance or overhaul a BP in the interest of making it more efficient and decrease its operational costs. Commonly BPs are process models depicted as diagrams, but they can be illustrated in various forms, such as, plain text, computer readable files or simulations, etc. [10]. Process diagrams in essence are graphical delegations of process models. These diagrams are created by utilizing visual notations, that incorporate graphical symbols and analogous architecture rules. Graphical symbols are the embodiment of semantic constructs, which in turn characterize the conduct of distinctive symbols and by extent the conduct of the diagram itself [10]. Currently many distinct process modeling notations are used at different magnitudes, such as Petri Nets, Workflow Process Description Language (WPDL), Unified Modeling Language 2.0 [48], Activity Diagram (UML AD), Business Process Model and Notation (BPMN), Event Driven Process Chain (EPC), Yet Another Workflow Language (YAWL) and Integrated DEFinition Method 3 (IDEF3) [10],[49],[50]. Given the existence of various modeling notations, a process model can be depicted by employing any of these notations, producing the same or disparate views of a process, such as its sequence or data flows. As an illustration, BPMN diagrams are able to combine the different views (sequence and data flows) of a process in the same diagram [10]. Among these process modeling notations and their respective complexity measures, Polancic and Cegnar focused their search mainly on the three that are most commonly used: BPMN, UML and YAWL. The reasoning behind this choice was, that all three include analogous diagram elements that embody the same semantic constructs, while UML (ISO/IEC 19501) and BPMN (ISO/IEC 19510) are also standardized by the International Organization for Standardization [10]. Nevertheless, if a measure had the capability of possible application to any of the other modeling notations, it has been included in the summary of metrics. Meaning that equivalent to the aforementioned metrics have the capacity to be possibly implemented to any analogous process model notation to BPMN, UML or YAWL (e.g. IDEF3 or EPC) [10].

## Complexity of Process Models

In this sub-section, we briefly analyzed the complexity concept of process models. According to Polancic and Cegnar, it is a well investigated term appearing frequently in the existing literature with several distinct definitions [10]. The adjective “complex”, is described as *consisting of many different and connected parts, not easy to analyze or understand; complicated or intricate*, in the Oxford web dictionary. In a similar manner the definition provided by Cardoso [7] earlier, is a deduction that emanates from the corresponding interpretation regarding process complexity given by the IEEE Standard Glossary of Software Engineering Terminology : **“the degree to which a process is difficult to analyze, understand or explain. It may be characterized by the number and intricacy of activity interfaces, transitions, conditional and parallel branches, the existence of loops, roles, activity**

**categories, the types of data structures and other process characteristics"** [7]. However, there are various approaches for this term, for instance Edmonds set a strict distinction between the complexity of a real process and the complexity of its analogous model [51]. He associated the difficulties related to understanding the notation that was employed to depict the model, with the complexity of a model. Additionally, he explained in detail that complexity relies on the category of considered difficulty, which in turn relies on the modeling goals [51]. Therefore, Edmonds characterized process model complexity as: **"That property of a language expression which makes it difficult to formulate its overall behavior, even when given almost complete information about its atomic components and their inter-relations".** Leading to the conclusion, that the complexity of a real process is quantified indirectly by calculating the complexity of its corresponding model, that is depicted with the help of a process modeling notation or diagram method [51]. Given the fact that a process diagram represents a directed and ascribed graph, the complexity of a BP diagram in its core is directly indicated by the quantity of diagram elements and the interrelations that occur between them [52]. The understandability of any diagram is strongly connected to the quantity of its elements, since it is mandatory for the reader to fully comprehend them if his goal is to grasp the meaning of the diagram altogether and ultimately the structure of the BP it illustrates [53]. When the modeling of existing BPs (i.e.AS-IS) in the form of diagrams is carried out, the complexity of the process itself cannot be altered, however the overall understandability of the resulting diagram is able to be enhanced (e.g., simplifying complex sections). On the other hand, when planning and modelling fitting (i.e.TO- BE) BPs, not only the complexity of the resulting diagrams cannot be set, but the complexity of the real process is directly affected as well [10].

## Complexity Measures and Quantification

The process of measurement in its essence is defined as the action of attaching numbers or symbols to the attributes (in this case complexity) of entities in the real or abstract world (e.g. BPs), in such a manner that explains these attributes in agreement with precise scientific rules [54]. There are several distinct approaches when attempting to quantify the complexity of a process model, that rely on their respective theoretical backgrounds (i.e. cognitive science, graph theory or software engineering)[10]. Although, the observable value resulting from the process of quantification is metric, the relation between a measure and a meaning to that value is established by employing human judgment [55]. The researchers involved in the domain of metrics largely agree upon a three-stage-method, in order to characterize and substantiate a new metric [56]: (a) metric definition, (b) theoretical validation of the metric and (c) empirical validation of the metric (Fig.33). However, there is a fourth nonobligatory stage which necessitates the development of an IT tool in pursuance of automatizing metric computations [10]. In accordance with Fenton and Pfleeger's design for software measure characterization, the process involves three phases [57]: (a) establishing the entity to be measured (in our case a BP model) , (b) selecting the entity's requested attributes that will be calculated (e.g. the size of a process model) and (c) defining the metric (e.g. number of activities or gateways in a process model). The quality of a metric can only be evaluated, after its definition stage is complete [10].

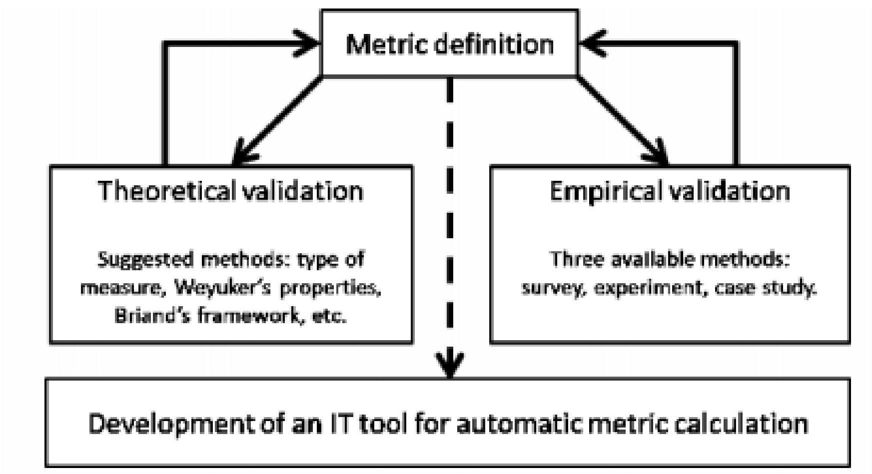


Figure 33: The process of defining and validating a new metric [56]

## Quality characteristics

The quality of metrics varies, since it is relies on how accurately it describes an entity's attribute [10]. Therefore, Latva-Koivisto specified the traits that a good complexity metric needs to embody [10], [58]:

- Validity: The metric quantifies the attribute it was designed to quantify.
- Reliability: When different observers measure the same process model, the resulting outcomes need to be agreeing.
- Computability: The calculation of the metric's value can be conducted by a computer program, ideally quickly.
- Ease of implementation: The additional difficulty introduced by applying the method that calculates the complexity measure should be within moderate limits.
- Intuitiveness: Comprehending the definition of the metric is relatively easy and identifying the connection it has to the inherent concept of complexity.

- Independence of other related metrics: Preferably, the metric's value does not depend on other model properties that in some occasions relate to complexity, including at least size and visual illustration of the process.

Given the fact that process models are graphs in essence, their complexity can also be assessed by taking into account the aspects of graph complexity metrics [51]:

- A good metric should be applicable to cyclical graphs, able to measure the complexity of repetitive processes.
- Modularity: Capability to integrate the aggregated complexity of a process from the sub-processes it includes.
- Additivity (specialized case of modularity): Capacity to aggregate the complexities of consecutive graphs in order to get the complexity of the entire process. However, its practicality is not resolved yet, since complexity measures can be used in conjunction with a metric that regards the size of the process graph.
- Independence of the level of detail in modeling a process: This particular type of independence may not be accomplished comprehensively, and its practicality is rather unclear. Nevertheless, it seems logical that a specific complexity metric for two homomorphically (two objects are deemed homeomorphic if they are able to transform into each other after a continuous and invertible mapping is implemented) equivalent graphs should have the same value, since breaking down or combining successive activities into smaller or larger ones respectively, does not imply any significant changes on the innate complexity of a process.

## Validation

Measurements for metrics need to be validated in order to safeguard that the data acquired from the measurement is indeed accurate and correct ,securing that a metric actually quantifies the attribute it was intended to measure [10]. The main problem that arises when a new metric is being defined, is the conversion of abstract notions into quantifiable definitions. This procedure may initiate undesired conflicts between the two. Therefore, validating a quantifiable notion is not an insignificant process, as three problems directly related to validation need to be resolved: (a) content validity, (b) criteria validity and (c) construct validity [8]. When examining the assessment of measurement notions, reliability is yet another concept that needs to be addressed. In essence, it addresses the consistency through time of a measurement notion and the entities it was designed to measure, including also its correctness and the rate of its decisiveness. A metric can be reliable and invalid at the same time, but an unreliable metric will never be valid [8].

## Theoretical Validation

In the existing literature, primarily three methods can be found that are employed in order to validate the theoretical background of a metric [10]: (a) properties resulting from the metric's category regarding its measurement scale (i.e. absolute, interval, nominal, ordinal, ratio) [56] (b) metric compliance with Briand's framework settings [59] and (c) metric compliance with Weyuker's settings [60]. By contemplating on these methods, we can determine if the metric's architecture is correct and whether it complies with measuring theory. As an illustration, Cardoso [61] utilized Weyuker's settings [60] to validate a metric theoretically. Despite the fact that these properties' initial designation purpose was the assessment of complexity metrics related to programming code, they can also be employed to assess complexity metrics of processes and their corresponding process models [10]. When a complexity metric satisfies every property of the nine defined by Weyuker, it is viewed as a good metric [60]. Alternatively, the theoretical validation of a metric can be achieved by utilizing the Briand et.al. framework [59], which was designed to evaluate programming code metrics mainly. In agreement with the framework, metrics are organized into five distinct groups, based on what they quantify: size, length, complexity and cohesion or coupling, with every group including particular properties the metric needs to be in compliance with. Process complexity is directly related to these five categories [10].

## Empirical Validation

Validating empirically a metric endorses the theoretical affirmation. To support that purpose, researchers employ various empirical research techniques, such as surveys, experiments and case studies [10]. The aim of empirical validation is to discover whether a metric quantifies in fact what it was designed to quantify. Both validations are needed for a metric to ensure its structural foundations are correct and its feasibility [56].

## Metric Thresholds

Although complexity metrics provide us with an empirical value, by itself is not yet enough in order to assess the degree or strength of the measured attribute. It becomes suitable after it is compared with another value or a metric's threshold (limit). Therefore, establishing thresholds for every metric that highlights the strengths of a quantified attribute, is highly beneficial [10]. In current literature, various techniques for threshold extraction are defined. Sanchez-Gonzalez et. al. [62] compared two of the most prevailing methods : ROC (Receiver Operating Characteristic) curves and the Bender method. Both of these techniques appear to be suitable for threshold extraction, although according to the authors ROC curves seem to be more efficient in particular cases [10].

## Distinct Complexity aspects of BP models

Categorizing the various complexity metrics of process models can be carried out in numerous manners, a process that largely depends on their evaluation and approach [10]. Cardoso [61] and Cardoso et.al. [63], indicated the leading aspects of workflow complexity in a way that resulted in four separate categories based on fundamental model traits: (a) activities ( related to the amount of activities included in the diagram), (b) control-flow (directly relates to the order of the activities in a model, such as arcs or sequence-flow),(c) data-flow ( related to the informational facet above the control flow) and (d) resources (related to human or computer resources and their specific role in carrying out the assigned activities) [10].

## Table of Complexity Metrics

Having concluded our theoretical analysis on complexity metrics, this subsection is dedicated to presenting them while providing all the vital information, in a clear and consistent manner. The metrics will be presented with the use of a table, that is going to be an adaptation of Polancic and Cegnar's[10] respective metrics table. The first column (#) stands for a unique identifier for each metric and the second represents the metric's name and its acronym (if available). Third column represents the theoretical foundations of the metric. The fourth column signifies (with '+') the types of constructs that were taken into account regarding a metric: activities (A), control-flow (CF), data-flow (DF) and resources (R). The next column labeled "Validation of the metric" combined with its analogous source, signifies if the metric has been validated theoretically (T) or empirically (E). The last column represents the primary source (definition) of the metric. The metrics are not listed by following any specific rules, starting with the most simplistic ones and working our way through towards derived (based on other complexity metrics) and composite metrics ( which are the result of combining at least two other metrics) [10]. In the case of absence of reliable data, the respective cell will be blank.

Table 3. 1: Complexity Metrics [10]

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 1 | (NOA, also NT) Number of activities / tasks | (LOC) Lines of code | + | | | | | | [63] |
| 2 | (NOAC) Number of activities and control -flow elements | | + | + | | | | | [63] |
| 3 | (NOAJS) Number of activities, joins and splits | | + | + | | | | | [63] |
| 4 | (CFC) Control -flow complexity | (MCC) McCabe's Cyclomatic Complexity | | + | | | [7],[ 8] | [64], [65] | [66] |
| 5 | (HPC) Halstead -based Process Complexity | Halstead Complexity Measure | + | + | + | | | | [63] |
| 6 | (IC) Interface Complexity (Fan-in & Fan-out) | (PC - Procedure Complexity) Information Flow by Henry & Kafura | | | + | | | | [63] |
| 7 | (CNC) Coefficient of Network Complexity | Graph theory, Kaimann, Pascoe | + | + | | | | [58], [67] | |
| 8 | Split-join ratio | Petri nets | | + | | | | | [68] |
| 9 | (ND) Nesting depth | Software complexity | | + | | | | [67] | [68] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 10 | Cognitive Complexity | (CFS) Cognitive Functional Size by Shao & Wang and cognitive load theory | + | + | | | | | [69] |
| 11 | Diameter | Graph theory | | + | | | | [62], [67] | [62] |
| 12 | Density | Graph theory | | + | | | | [53], [62] | [62] |
| 13 | (AGD or ACD) Average Gateway (or Connector) Degree | Information flow metric by Henry & Kafura | | + | | | | [53], [62], [67] | [62] |
| 14 | (MGD or MCD) Maximum Gateway (or Connector) Degree | Information flow metric by Henry & Kafura | | + | | | | [62] | [62] |
| 15 | (GM, also MM) Number of Handles or Gateway / Connector Mismatch | Gurh et. al., Mendling et al. | | + | | | | [53], [62], [67] | [62] |
| 16 | (GH, also CH) Gateway / Connector Heterogeny | Mendling et al. | | + | | | | [53], [62], [67] | [62] |
| 17 | Sequentiality | Graph theory, Mendling et al. | | + | | | | [62], [67] | [62] |
| 18 | Separability | Graph theory, Mendling et al. | + | + | | | | | [62] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 19 | (TS) Parallelism | Mendling et al. | | + | | | | [62] | [62] |
| 20 | (CYC) Cyclicity | Graph theory, Mendling et al. | + | + | | | | [62], [67] | [62] |
| 21 | (TNSF) Total number of sequence flows | Basic elements of a model / diagram, Rolón | | + | | | | [62] | [62] |
| 22 | (TNE) Total number of events | | | + | | | | [70] | [62] |
| 23 | (TNG) Total number of gateways | Basic elements of a model / diagram, Rolón | | + | | | | [70] | [62] |
| 24 | (NSFE) Number of sequence flows from events | | | + | | | | [71] | [62] |
| 25 | (NMF) Number of message flows | | | | + | | | [62] | [62] |
| 26 | (NSFG) Number of sequence flows from gateways | | | + | | | | [62] | [62] |
| 27 | (CLP) Connectivity level between pools | | | + | | | | [62] | [62] |
| 28 | (TNDO) Total number of data objects | | | | + | | | [62] | [62] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 29 | (NID) Number of inclusive decisions | Basic elements of a model / diagram, Rolón | | + | | | | [62] | [62] |
| 30 | (NPF) Number of parallel forking | Rolón | | + | | | | [70] | [62] |
| 31 | (NP) Number of pools | Basic elements of a model / diagram, Rolón | | + | | | | [62] | [62] |
| 32 | (NCD) Number of complex decisions | Rolón | | + | | | | | [62] |
| 33 | (NEDDB) Number of exclusive gateways based on data | | | + | + | | | [70] | [62] |
| 34 | (NEDEB) Number of exclusive gateways based on events | Basic elements of a model / diagram, Rolón | | + | | | | [62] | [62] |
| 35 | (NIMsE) Number of Intermediate Message Events | | | | + | | | [70] | [72] |
| 36 | (NEMsE) Number of end message events | | | | + | | | [70] | [72] |
| 37 | (TNCS) Total number of collapsed processes | | + | | | | | [70] | [72] |
| 38 | (CLA) Connectivity level between activities | | + | + | | | | [70] | [72] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 39 | (CI) Complexity index | Graph theory | + | + | | | | [58] | [58] |
| 40 | (RE or RT) Restrictiveness Estimator | Graph theory | + | | | | | | [58] |
| 41 | (ECaM) Extended Cardoso metric | CFC metric by Cardoso | | + | | | | [67], [73] | [73] |
| 42 | (ECyM) Extended cyclomatic metric | Cyclomatic complexity by McCabe | + | + | | | | [73] | [73] |
| 43 | Anti-patterns | Anti-patterns from software engineering | + | + | | | | | [74] |
| 44 | Knot count | Number of knots in software code | | + | | | | | [74] |
| 45 | (LBC) Log-Based Complexity | Cardoso | + | + | | | | | [75] |
| 46 | ((A)VG) (Average) Vertex degree | Graph theory | | + | | | | | [8] |
| 47 | (CUDP) Quantity of Decisions to be made per pool/participant | Structural elements of BPMN, Debnath et al. | | + | | + | | | [76] |
| 48 | (CTP) Quantity of tasks executed in a specific pool/participant | Structural elements of BPMN, Debnath et al. | + | | | + | | | [76] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 49 | (CTSP) Quantity of tasks of a swim-lane of a pool | Structural elements of BPMN, Debnath et al. | + | | | + | | | [76] |
| 50 | (PTP) Proportion of task distribution per participant | | + | | | + | | | [76] |
| 51 | (PTSP) Proportion of tasks per swim-lane of a specific pool | | + | | | + | | | [76] |
| 52 | (NSBPart) Quantity of sub processes per pool | | + | | | + | | | [76] |
| 53 | (NFPart) Quantity of Message Flows between two pools | | | | + | | | | [76] |
| 54 | (DSP) Durfee Square Metric | Durfee's square from number theory | + | + | | | | | [77] |
| 55 | (PSM) Perfect Square Metric | Durfee's square from number theory and g--index by Egghe | + | + | | | | | [77] |
| 56 | (CADAC) Cognitive Activity Depth Arc Control Flow | Cognitive weights, IC metric and nesting depth | + | + | + | | [78] | [78] | [78] |
| 57 | Structural complexity by Cheng | Graph theory and Shannon's information entropy | + | + | | | | | [79] |
| 58 | Interaction Complexity by Cheng | Shannon's information entropy | | | + | | | | [79] |

| # | Metric Name | Related Metrics | Considered Constructs | | | | Validation of the metric | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | | | A | CF | DF | R | T | E | |
| 59 | Usability Complexity by Cheng | BPA-GOMS (Business Process Analysis - Goals, Operations, Methods and Selection rules) | | | + | + | | | [79] |
| 60 | Total Operational Complexity by Cheng | The three-above metrics (57,58,59) by Cheng | + | + | + | + | | [79] | [79] |
| 61 | GQM-based Complexity Metrics | Goal-Question-Metric (GQM) | + | + | | | | | [80] |
| 62 | (SM) Structuredness metric | Graph theory and Petri nets | + | + | | | | [56], [67], [73] | [73] |
| 63 | (CC) Cross-Connectivity | Cognitive complexity (Cognitive Dimensions Framework) | | + | | | | [56], [81] | [81] |
| 64 | (P*D*S) Complexity Model by Cheng and Prabhu | CFC metric, Halstead complexity metrics and process size | + | + | | | | [82] | [82] |
| 65 | Antonini et. al. Business Process Metrics | NOA, CFC, routing tasks | + | + | + | + | | | [83] |
| 66 | (GCI) Gateway Complexity Indicator | CFC, GM, GH, AGD, MGD and TNG metric | | + | | | | | [84] |
| 67 | (DoAF) Degree of Activity Flexibility | Basic elements of a model / diagram, Rolón | + | | | | | [3] | [3] |

## DoAF: A new internal measure

Tsakalidis et.al.[3], introduced a new internal complexity measure to the BPR domain, named Degree of Activity Flexibility (DoAF). This metric was defined in the following manner: it expresses the ratio of unconstrained activities of a BP model to the total amount of its activities.

$$DoAF = 1 - \frac{NOcA}{NOA}$$

Figure 34: DoAF complexity metric [3]

Where NOcA stands for the total of constrained activities and NOA stands for the total number of activities [3]. The motivation behind the need to create such a metric, derives from the fact that if a model exhibits numerous constraints between its activities, it may cause BPR to be less effective when applied or even increase its implementation complexity to a higher level than originally anticipated. Therefore, a crucial criterion in order to apply redesign heuristics to BP models is the degree of constraint exhibited by the activities of an input model [3].Among the different types of constraints that exist in the current literature, the creators of this metric focused on the ones that affect chiefly the relations between activities, while excluding any constraints that have a contradictory purpose to those that were chosen. In order for this matter to be resolved, Tsakalidis et.al. selected a subset of non-exclusive constraints [3]:

| Explicit Constraints | Implicit Constraints |
|---|---|
| init(a) | coexistence(a,b) |
| last(a) | xor_existence(a,b) |
| precedence(a,b) | or_existence(a,b) |
| chain_precedence(a,b) | |

Figure 35: Subset of Model Constraints for the DoAF metric [3]

According to the definitions and limitations set by Tsakalidis et.al. [3],*coexistence (a, b)* constraint accounts only for activities that are placed in different branches of an AND gateway, instead of taking into account all the possible dyads of activities executed during the runtime of a process. If two tasks are positioned in different branches of an OR or XOR gateway, Tsakalidis et.al.[3] defined *or_existence(a,b)* and *xor_existence(a,b)* respectively. These two constraints signify that activities "a" and "b" belong to different branches of an OR or XOR gateway accordingly [3].

## 3.4 Threshold Extraction Methods

Concluding our literature review, this chapter is dedicated to analyzing the various threshold extraction methods, relevant to BP measures, in detail. Given the fact that, extracting thresholds is a complex research task which requires strong theoretical and practical foundations, in accordance with [11] numerous methods exist that serve this purpose. The methods that are commonly employed for BP measures, rely heavily on statistical tools such as standard deviation, mean, clustering or ROC curves [84], but the majority of these techniques and tools come with some inherent flaws.

### K-means Clustering

Yoon et. al. [85] suggested the execution of a k-means cluster algorithm in order to observe deviations regarding software measurement data. In agreement with [86], k-means clustering is an independent technique with the capability of supporting high-dimensional data [85]. Assuming a data matrix is formed that consists of variables and observations, our main goal would be to cluster these observations into groups that are comparable on the inside and dissimilar from group to group [87]. The *k* of this method signifies the total amount of groups and is determined based on theory, by experts. In order to work out the scale of homogeneity and heterogeneity, this technique utilizes the Euclidean distance as a means to determine the similarity among the observations existing within the various groups [85].The Euclidean distance function D ,as it was defined by Euclid:

$$D = \sum_{i=1}^{k} \sum_{j \in S_i} |x_j - \mu_i|^2$$

Figure 36: Euclidean distance function

Where k is the total of clusters and **$S_{i,I}$ =1,2, …, k and $\mu_i$** is the centroid identifier or mean point of all the **$x_j$** points, where **$x_j$ E $S_i$**. Lastly in order to save space, the detail operational flow of the k-means algorithm was omitted. Yoon et.al. defined these deviations as outliers, referring to software data that is contradictory to the majority of it [85]. Hodge and Austin [86] pointed out that when a point is located outside of all the clusters, it is defined as an outlier. Therefore, Yoon et.al. reformulated the meaning of an outlier by establishing the two categories of external and internal outliers [85]:

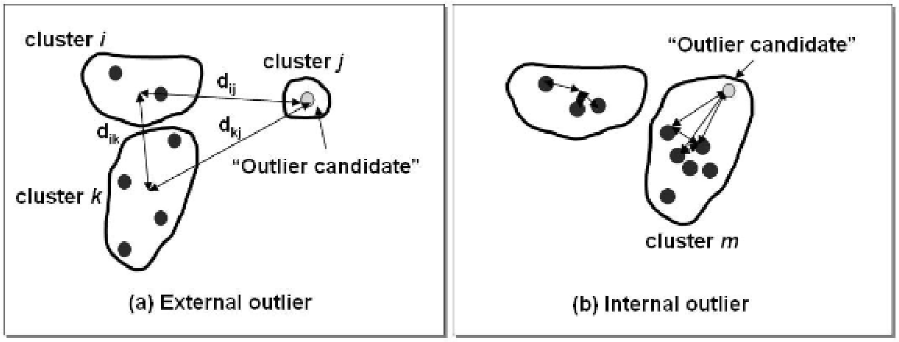


Figure 37: External & Internal outliers [85]

By employing the Euclidean distance function D, it is relatively easy to deduce why the gray elements fall under the definition of outlier.

Fotoglou et.al. employed this method on an archive of 1000 process models in order to categorize them to conclusive clusters correlating to complexity levels [88]. Weighted significance was appointed to certain complexity metrics regarding the creating of custom model classifications, in order to extract threshold values [3]. However, there was an inherent weak point in this method. The total amount of clusters to be formulated by the algorithm, was an input specification provided by the authors and additional subdividing regarding the complexity levels ,would generate disparate outcomes [3].

## ROC (Receiver-Operating Characteristic) Curves

In its essence, ROC is a diagnostic accuracy test [89]. This technique can be employed to evaluate the quality of information ,contributed by the categorization of classes, into a binary division by utilizing a single metric [90].In order to plot the ROC curve, two variables need to have been defined beforehand: one binary (i.e. 0 or 1) and one continuous. Once a range of threshold values has been set for each one of the metrics, the classification table (confusion matrix) is formed for every threshold value, and each one of these tables generates a point on the ROC curve [90]. The entirety of these points are pairs of Sensitivity and (1- Specificity) values. Congregating as many such pairs as possible will result in completing the ROC graph, i.e., detecting all the pairs for every metric value from the minimum to the maximum. These dyads signify the classification performance of the threshold value that generated each one of them, while the dyad that produced the best performance highlights the best threshold value to use in practice [90].Sensitivity and specificity values can be gauged from the confusion matrix in the following manner:

**Sensitivity= *tp* rate= TP/P, Specificity=1-*fp* rate= 1-FP/N**

| | Actual | |
|---|---|---|
| Classified | Faulty | Not-faulty |
| Metric $\geq$ threshold | True-positives (TP or correct alarms) | False-positives (FP or false alarms) |
| Metric<threshold | False-negatives (FN or missed alarms) | True-negatives (TN or no alarms) |
| Totals | P | N |

Figure 38: Confusion matrix based on threshold value [90]

The test performance is determined by using the Area Under the ROC Curve (AUC). It is a broadly utilized measure that classifies performance and varies from 0 to 1 and its main purpose is the assessment of how good the threshold values are at discerning the groups [62]. The rules of thumb generally used in terms of evaluating the differentiated power of metrics based on AUC are: If an AUC<0.5 then is viewed as no good, poor if AUC<0.6, fair if AUC<0.7, acceptable if AUC<0.8, excellent when AUC<0.9 and outstanding if AUC<1. A 95% confidence interval is employed to gauge the p-value (standard error) and the test is considered valid if the AUC differs substantially from the value 0.5 [62].Altering the lower threshold values would intensify the prediction ratio of the true-positives (benefit), but would also increase the false-positives prediction ratio (cost), i.e., more hits, but additional false alarms. On the other hand, altering threshold values in the adverse direction would lower the false-positives prediction ratio but would also cause a proportional decrease regarding the prediction ratio of true-positives: less false alarms, resulting in fewer hits [90]. Therefore, a benchmark needs to be set when it comes to selecting a threshold value for a metric (sensitivity, 1-specificity dyad), in order to ensure that there is a balance between benefits and costs. Typically, the criterion that serves this purpose is selecting the pair that possesses the highest value for both sensitivity and specificity values. Namely, our end goal is to minimize false-positives and false-negatives simultaneously [90]. ROC analysis is highly effective when the data exhibits errant distribution and/or disproportionate classification error costs. It also plays an important role in studies that utilize a cost-sensitive categorization, specifically when the classes are irregular [91]. ROC curves remain unaffected by any changes regarding data distribution, mainly due to the fact that they depend solely on the true positives and negatives, which both take into account the cells of the confusion matrix (Fig.38) [90]. However, the main limitation in [90] was that the ROC analysis did not succeed in extracting monotonic thresholds [3]. In a different proposal [92], ROC curves turned out to be effective in terms of threshold extraction for BP performance indicators. One of the drawbacks was that by applying ROC curves, caused the negative aspects of other statistical methods to be alleviated. Eventually this alleviation resulted in the prerequisite of setting numerous input parameters values, that ultimately could generate unrealistic outcomes when these parameters are set poorly [3].

## Bender Method and Binary Logistic Regression

A well-established and extensively employed technique to extract thresholds, is the Bender method. So far this method has been utilized in studies, in order to evaluate the magnitude of which an explanatory factor has a threshold effect upon a definitive response variable [93]. It is broadly implemented for the sole purpose of extracting thresholds in epidemiological studies ([94],[95]), software engineering ([96],[97],[98]) and decision making regarding the BP domain ([99],[100],[101]). The Bender method is based on a simple principle, namely it assumes that the risk of an event to occur is continual below a distinct threshold and intensifies based on a logistic equation. Once agreeable levels regarding absolute risk have been delineated, the equivalent benchmark risk factor values can be computed using non-linear functions of the alpha and beta logistic regression coefficients [3],[62]. A vital step when implementing the Bender method is applying the Binary logistic regression model which in essence is a statistical method, utilized for assessing the probability of binary choices. In our thesis, the binary variable ***plasticity*** will take the values of if a process model ***is able/not able to be redesigned*** prior to BPR implementation (1 and 0 respectively). Logistic regression focuses on the principle, that this probability has the capacity to be represented by the odds. Namely the ratio of the probability that deems a model as plastic, divided by the probability of characterizing it as non-plastic [62]. These odds are determined by the logit function which is:

$$Logit(p_i) = \alpha + \beta_1 x_{1i} + \ldots + \beta_k x_{ki}$$

Figure 39: Logit Function [62]

Where $\alpha$ is the intercept and $\beta_1$, $\beta_2$, $\beta_3$ (and so on) are called the regression coefficients of the independent variables $x_{1i}$, $x_{2i}$, $x_{3i}$ accordingly. In our study, ***k*** BP model metrics will be considered as input values and observations from ***i*** BP models. Regarding benchmark values, generally speaking, are distinctive points of the dose-response curve signifying that the risk of an event occurring rises precipitously [62]. However, defining what is meant by the term "precipitously" has some inherent difficulty. Therefore, a benchmark can be described as the "Value of an Acceptable Risk Level" (or VARL) and can be estimated in the following manner:

$$VARL = \frac{1}{\beta}\left(\ln\left(\frac{p_0}{1-p_0}\right)-\alpha\right)$$

Figure 40: Value of an Acceptable Risk Level [62]

Where $p_0$ stands for the probability of an event occurring. This value is determined by the expert who is implementing the Bender method and varies from 0 to 1 [62]. For instance, hypothesizing that $p_0$=0.7 expresses the probability of the measures to be deemed as appropriate equal to 0.7, with $\alpha$ and $\beta$ as the coefficients of the logistic regression equation portrayed in Fig. 39. The measures for which we aim to estimate the thresholds, are characterized as the independent variables in the logistic regression model. Albeit, one limitation of this method is that it requires a binary variable as the dependent variable, which in our case is the plasticity variable [62].

## 3.5 Chapter Summary

Upon reaching the completion of the 3rd Chapter of our thesis, a brief summary to highlight its critical points is necessary. Our analysis began with the Devil's Quadrangle, since it has the capability to evaluate the distinct impacts that a redesign endeavor may bring on process model. The next step was an examination of the 29 different redesign best practices and their 8 separate internal categories, based on the viewpoint each category assumes in terms of the redesign effort it aims to achieve. Proceeding with our analysis the model of Plasticity along with any related notions and model measures were examined comprehensively, to signify the reasons that differentiate Plasticity from its related concepts. Process model complexity metrics hold a substantial role in our thesis, and naturally they were the next key concept we delved into, including a detailed presentation of the complexity model measure, its related notions and its 67 distinct metrics that are currently available on the related literature. Lastly, the 3 prevailing threshold extraction mathematical methods were reviewed to highlight their advantages, disadvantages, limitations as well as their applicability and/or suitability in terms of their implementation on research projects.

# 4. A Comprehensive Framework for Plasticity

This chapter is dedicated to the steps that we followed in order to visualize, achieve and synthesize a desirable framework for the model of Plasticity. It is a necessity for the following stage (Ch.5) which is to carry out the necessary experiments and ultimately validate it in an effective, comprehensive and efficient manner.

## 4.1 Selecting an appropriate redesign method

According to the 2nd Chapter of our thesis, there is a considerable amount of redesign methods as portrayed in " The Redesign Orbit" (Fig.2) [4]. In order to choose a method that fits our experimental goals, first we had to consider the desired magnitude of the redesign initiatives set in our mind. Therefore, since the main goal was set upon optimizing existing process models in terms of bottlenecks, inconsistencies and modelling errors they may have, a Transactional method is the obvious choice. Given the fact that one of our primary goals is, to use mathematical tools and/or methods in order to support the various redesign stages, the method needs to be Analytical in its nature. The last critical factor affecting our choice is the desired viewing point we assumed, which in our case is that of the organization that hosts the BP that places the concerns interests of the organization in the spotlight [4]. There are 5 possible choices in this "sub-sphere" included in "The Redesign Orbit" (Fig.2) (i.e., Transactional, Analytical and inward-looking methods), however given its wide selection of 29 redesign heuristics (best practices) we opted to select the Heuristic Process Redesign (HPR) method.

## 4.2 Selecting an appropriate redesign heuristic

According to Reijers and Mansar [2], there are 29 documented and well-established redesign heuristics included in the HPR method. Given the fact that this research is partially an effort to expand the research of Tsakalidis et.al. [3] on the RESEQ heuristic, our choice for an appropriate redesign heuristic is the Parallelism (PAR) best practice. However, there is an additional reason that led us to select this heuristic specifically. The parallelism best practice belongs in the ***Business process behavior*** category that focuses on when the workflow is executed. In particular, choosing a heuristic from that category assists us with the identification of bottlenecks, inconsistencies and/or modelling errors that a process model may have, in a direct manner during its runtime. By investigating the applicability of the PAR heuristic as a redesign solution, the newly redesigned models ideally will reap the benefits of its application according to its evaluation presented with help of the Devil's Quadrangle (Fig.16) [2].

## 4.3 Selecting appropriate complexity metrics

According to the Table 3.1 [10], there are 67 distinct complexity metrics that measure different types of complexity aspects on a process model. In our thesis, the primary goal is to select those metrics that are directly related to the PAR heuristic. Specifically, in order to obtain conclusions of value, the following metrics were selected to assist us with the evaluation of the Plasticity model ,for several process models (Table 3.1) [10]:

- **Sequentiality (Ξ)**
- **Connectivity Level between Activities (CLA)**
- **Control-flow complexity (CFC)**
- **Coefficient of Connectivity (CNC)**
- **Number of Activities/ Tasks (NoA, or NT)**
- **Number of Activities, Joints and Splits (NoAJS)**
- **Number of Sequence flows between Activities (NSFA)**
- **Number of Sequence Flows from Gateways (NSFG)**
- **Total Number of Gateways (TNG)**
- **Token Split (TS)**
- **Degree of Activity Flexibility (DoAF)**
- **Average Gateway Degree (AGD)**
- **Gateway Heterogeneity (GH)**

## Internal metrics for assessing PAR

By selecting a subset of measures including their respective definitions, we aim to predict the plasticity of the input models. Namely, the quality trait that refers directly to the ability of a model to be easily transformed or reshaped. The complexity metrics that were elected previously, primarily focus on activities, gateways and the control flow complexity to and from gateways, in order to determine if any correlations exist between them and the model of plasticity. Hypothetical correlations between plasticity and a metric, are illustrated with the use of brackets as (+) for a positive correlation and (-) for negative correlation. The selected measures are:

- **Sequentiality (Ξ) (+)**: This measure is employed in order to quantify the degree to which a process model consists of pure sequences of tasks and is defined as the amount of sequence flows between non gateway nodes divided by the total amount of sequence flows. When a process model is sequential, the ratio of Ξ is equal to 1. Therefore, the hypothetical correlation is positive given the fact that models which exhibit higher Sequentiality are better candidates for the implementation of the parallelism heuristic.
- **Connectivity Level between Activities (CLA) (-)**: This measure represents the ratio between the total amount of activities and the total number of sequence flows between activities. We hypothesize that there is a negative correlation between CLA and plasticity, due to the fact that the parallelism best practice is applied more efficiently in process models with higher amounts of sequential tasks, which in turn entails a relatively high amount of sequence flows between activities.
- **Control-flow complexity (CFC) (-)**: Defined by Cardoso [65], this metric measures the complexity of split gateways based on the number of mental states that a designer needs to consider when he models a process. Higher control flow complexity indicates less Sequentiality (Ξ) within a process model, which affects directly the applicability of the parallelism heuristic.
- **Coefficient of Connectivity (CNC) (-)**: This measure directly relates to the ratio of the total number of arcs (sequence flows) in a process model to its total amount of nodes (nodes are equal to the total number activities, gateways and events of a process model), capitalizing on the concept of connectivity between elements in order to quantify the model's structural complexity. Higher values of this metric, indicate a dense model with increased complexity and error probability [8]. Our hypothesis in this case is that a negative correlation exists, meaning that models with lower CNC are more susceptible when it comes to applying the parallelism best practice.
- **Number of Activities/ Tasks (NoA, or NT) (+)**: This metric produces the final number of activities/tasks in a given process model. Subprocesses are regarded in their collapsed form and the metric does not take into account activities that belong in expanded subprocesses. Higher values of this measure signify higher chances that a model will contain tasks which are unconstrained and therefore can be put in parallel with others.

- **Number of Activities, Joints and Splits (NoAJS) (-)**: This measure calculates the total number of Activities, gateway joints and gateway splits in a process model. We argue that despite having a higher number of activities which indicates a higher probability to apply the PAR heuristic, having high amounts of joints and splits signifies the existence of multiple gateways which in turn indicates a more complex and prone to errors model with an increased number of constrained activities. Given that, our hypothetical correlation is negative.
- **Number of Sequence flows between Activities (NSFA) (+)**: This measure computes the amount of sequence flows between activities that exist in a model. We hypothesize that a high NSFA value directly indicates a higher NoA value, which positively affects the possibilities to re-sequence activities in parallel with others by applying the PAR heuristic.
- **Number of Sequence Flows from Gateways (NSFG) (-)**: This metric calculates the number of sequence flows that begin from gateways in a process model. High NSFG values indicate higher control flow complexity and therefore our hypothetical correlation is negative, i.e., a model exhibits more opportunities to implement the PAR best practice if it has lower control flow complexity.
- **Total Number of Gateways (TNG) (-)**: This metric provides the final number of gateways in a process model. Assuming that models which contain larger amounts of gateway elements have an inherent limited capacity regarding the applicability of the PAR heuristic, since the activities the belong in gateway branches are constrained implicitly, we hypothesize that the correlation between plasticity and TNG is negative.
- **Token Split (TS) (-):** This measure sums up the output degrees of AND-join and OR-join gateways minus one. We argue that models with lower TS values exhibit increased possibilities regarding the implementation of the PAR heuristic, have less errors and less constrained activities.
- **Degree of Activity Flexibility (DoAF) (+):** This metric is defined as the ratio of a model's unconstrained activities, meaning not actively involved in any explicit or implicit constraints, to its total number of activities [3]. We argue that the hypothetical correlation between DoAF and the model of plasticity is positive, given the fact that a model with less constrained activities exhibits more opportunities to be redesigned.
- **Average Gateway Degree (AGD) (-)**: This measure calculates the average number of outgoing sequence flows from split gateways and is defined as the total outgoing sequence flows from

split gateways, divided by the total quantity of gateways in the model [8]. We assume that the hypothetical correlation between AGD and model plasticity is negative, provided the fact that models with higher values of AGD are denser and exhibit higher error probability.

- **Gateway Heterogeneity (GH) (-):** This internal measure produces the degree of gateway heterogeneity in a process model. In other terms, it computes the number which translates to the variety of gateways that have been utilized by the modeler, in order to model a process [8]. We assume a negative correlation between GH and the model of plasticity, since a process model with numerous and different types of gateways is more complex with a higher error probability.

## 4.4 Selecting an appropriate threshold extraction method

Due to the nature of our experiments, and in particular the fact that one of the questions that were asked in our research questionnaire for every process diagram was to assess each model's plasticity, regarding the difficulty to implement the PAR heuristic on a scale from 1 to 5. The subjects were asked to provide us with their subjective opinion on the question at hand, where 1 stood for the "very difficult" implementation option and 5 was assigned to the "very easy" implementation option respectively. Only one threshold extraction method from the three prevailing that were discussed earlier (subsection 3.3), fits our goals. Specifically, a combination of the Binary Logistic Regression and Bender methods is the short answer. Given the nature of the Plasticity variable, it is viewed as a perfect candidate to act as the dependent binary variable for the application of the Logistic Regression method, and therefore to detect which of the complexity metrics that were selected (subsection 4.3), directly correlate to the inherent plasticity of process models.

## 4.5 Planning the Experiments

After the establishment of our framework, our main concerns are primarily focused on the next steps regarding its implementation and validation: the familiarization of our subjects with the theoretical background of BPR and the model of Plasticity, carrying out the experiments in a manner that will produce credible and reliable data, collecting the aforementioned data and then performing the required mathematical approaches to generate respectable threshold values. Addressing our main concerns sequentially, the subjects participated in training courses in order to obtain the necessary theoretical background, according to Fig.41 which represents the exact timeline of the training courses and experiment dates in terms of when they occurred.

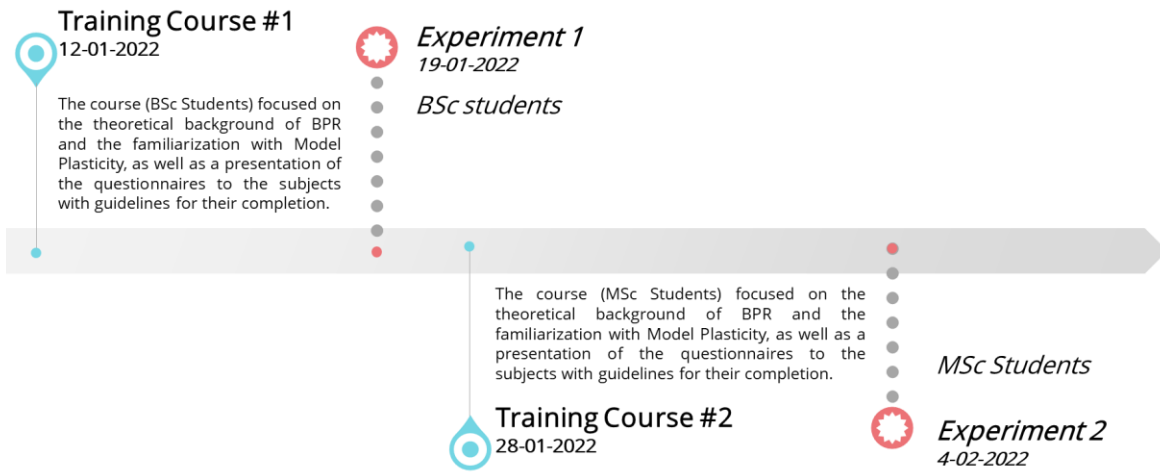


Figure 41: Timeline of training courses & experiments

Once our subjects were familiar with the theoretical background of BPR and the model of Plasticity on a satisfactory level, we presented them with the questionnaires they had to answer, while providing detailed guidelines to ensure that we would obtain as accurate answers as possible without any significant deviations. A more detailed overview of these questionnaires in terms of their quantity, constraints and types of questions is provided in the subsection 5.1. The next step was to collect all the data provided by our subjects and to carry out additional calculations regarding the complexity metrics we selected (subsection 4.3), in order to perform the necessary mathematical approaches towards the completion of our goal (subsection 5.2). In regard of the aforementioned threshold values (subsection 5.2), the next stage was to provide concrete validation for our framework. Therefore, with the use of four disparate process models from the current literature, we evaluated each one of these models in terms of their inherent capacity to be redesigned and/or remodeled with the use of the PAR heuristic (Ch. 6).

## 4.6 Chapter Summary

The 4th chapter of our thesis was primarily focused on selecting the appropriate redesign method, heuristic, complexity metrics and threshold extraction mathematical method in order to synthesize a desirable and comprehensive framework for the model of Plasticity. Every choice was driven by our main goal, which is to evaluate whether process models are efficiently plastic in terms of their overall complexity prior to conducting any redesign initiatives, by implementing the PAR heuristic on them. The procedure set in this chapter is vital, since the conduct of our experiments and every mathematical approach employed towards our goal to obtain relevant threshold values, are interrelated to the framework defined in this chapter.

# 5. Experiments

In the 5th Chapter of our thesis, a thorough analysis regarding the design and the experimental results of the experiments that were carried out will be performed. Starting with the design of the experiments entailing the total number of subjects, their background, the timeframe of our experiments and the form of the questionnaires presented to the subjects. Once every subject provided us with their answers, we collected all the relevant data and performed statistical analysis, as well as the binary logistic regression and Bender methods, that we selected in subsection 4.4 as a means to produce relevant threshold values regarding the metrics selected in subsection 4.3 in order to assess the redesign capacity of process models prior to inducing redesign initiatives on process models by applying the PAR heuristic (subsections 4.1,4.2).

## 5.1 Design of the Experiments

Following the procedure set in chapter 4, the data used in order to extract thresholds, was produced by the two experiments that were carried out earlier this year (January & February, 2022) and their capital purpose was to assess which internal model metrics directly affect the model of plasticity. The first experiment (Experiment 1) consisted of 27 BSc students in the Applied Informatics Department in their 3rd undergraduate year, while the subjects of the second experiment (Experiment 2) consisted of 28 BSc students in the same department and year and 19 MSc students (47 subjects in total) following the "Business Computing" specialization in the Applied Informatics Department. Before the experiments, the subjects participated in the necessary training courses that were conducted during the first half of January and the second half of January, in order to become familiar with the concept of plasticity and the implementation of the PAR best practice.

Ten BPMN models from literature were elected as the experimental material with varying amounts of activities and structural complexity (Table 5.1). Every model was accompanied by a list of explicit constraints and a questionnaire (3 questions per model) with assignments oriented towards the applicability of the PAR heuristic.

Our analysis begins with calculating the values of every complexity metric that was selected (Ch.4.3), for each one of the 10 models (Table 5.2). The models' NoA metric varies from 7 to 36 activities, while their TNG metric varies from 0 to 21 gateway nodes. Considering as well the observation that generally small to moderate sized process models serve as case studies in literature, our experimental material exhibits a sufficient variation in terms of size. Structural complexity exhibits an acceptable variation also, since the models' CFC and NSFG values vary from 0 to 19 and from 0 to 29 respectively. The values were rounded to two decimal places.

| No | Process Title | Reference |
|---|---|---|
| 1 | Incident Management Process | [102] |
| 2 | Concept Management Process | [103] |
| 3 | Account opening process in private banking | [104] |
| 4 | Patient Examination Process | [105] |
| 5 | Ordering Process | [106] |
| 6 | Admission Process | [107] |
| 7 | Boarding Process #1 | [108] |
| 8 | Programmed Surgical Patient Process | [109] |
| 9 | Boarding Process #2 | [110] |
| 10 | Airline Company | [111] |

Table 5. 1: BPMN Models used in the experiments

| No | NoA | NoAJS | AGD | Ξ | GH | CNC | TS | CFC | NSFA | NSFG | CLA | TNG | DoAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 9 | 3.00 | 0.44 | 0.00 | 1.00 | 0 | 2 | 4 | 3 | 1.75 | 2 | 0.29 |
| 2 | 8 | 11 | 3.33 | 0.38 | 0.00 | 1.15 | 0 | 6 | 5 | 5 | 1.60 | 3 | 0.50 |
| 3 | 10 | 14 | 3.00 | 0.27 | 0.00 | 1.06 | 0 | 4 | 4 | 6 | 2.50 | 4 | 0.20 |
| 4 | 12 | 12 | 0.00 | 1.00 | 0.00 | 0.88 | 0 | 0 | 10 | 0 | 1.20 | 0 | 0.33 |
| 5 | 13 | 14 | 3.00 | 0.77 | 0.00 | 0.94 | 0 | 2 | 10 | 2 | 1.30 | 1 | 0.46 |
| 6 | 16 | 19 | 3.33 | 0.50 | 0.00 | 1.10 | 0 | 6 | 10 | 6 | 1.60 | 3 | 0.19 |
| 7 | 14 | 17 | 3.00 | 0.50 | 0.28 | 1.05 | 1 | 4 | 9 | 4 | 1.56 | 3 | 0.00 |
| 8 | 19 | 22 | 3.33 | 0.60 | 0.00 | 1.21 | 0 | 7 | 15 | 6 | 1.27 | 3 | 0.05 |
| 9 | 19 | 25 | 3.33 | 0.39 | 0.28 | 1.11 | 2 | 11 | 11 | 9 | 1.73 | 6 | 0.42 |
| 10 | 36 | 57 | 3.00 | 0.20 | 0.30 | 1.11 | 9 | 19 | 13 | 29 | 2.77 | 21 | 0.28 |
| MEAN | 15.40 | 20.00 | 2.83 | 0.51 | 0.09 | 1.06 | 1.20 | 6.10 | 9.10 | 7.00 | 1.73 | 4.60 | 0.27 |
| SD | 8.33 | 13.93 | 1.01 | 0.24 | 0.14 | 0.10 | 2.82 | 5.49 | 3.73 | 8.12 | 0.52 | 5.99 | 0.17 |

Table 5. 2: Complexity metrics values of BPMN Models

After the values were computed, their standard deviation was calculated to confirm whether the measures exhibited acceptable variability in order to be included in the study. The GH, CNC and DoAF metrics (highlighted in yellow) displayed a standard deviation close to zero which signifies that the data points tend to reside close to mean value (limited variability). Due to their limited variability regarding their standard deviation in the selected 10 BPMN models, we opted to exclude the CNC, GH and DoAF metrics entirely from our study.

Each one of the 10 BPMN models was accompanied by a questionnaire and every subject was assessed, in accordance with the following objective data once they accomplished the tasks in every question: correct answers regarding plasticity, time elapsed, and efficiency established as the ratio of correct answers divided by the time elapsed. A personal opinion was also requested, regarding the difficulty to implement the PAR heuristic in every model on a scale from 1 to 5, where 1 stood for the "very hard" option and 5 the "very easy" option respectively. We hypothesize that the internal complexity metrics elected previously and the subjects' personal opinion are directly related to each other. Particularly, we express the assumption that the experimental subjects affirmed that putting eligible activities in parallel with others, namely applying the PAR heuristic, directly relates to the hypothetical correlations displayed in brackets (Ch.4.3) for every one of the elected metrics. Later in this thesis, a correlation analysis shall be carried out in order to prove the validity of this assumption. Table 5.3 presents the mean values of: Correct Answers (CA), Time elapsed (T), Efficiency (EF) and personal opinion on plasticity (PL) of all the subjects for each one of the 10 BPMN models.

| | Experiment 1 | | | | Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|
| No | PL | CA | T | EF | PL | CA | T | EF |
| 1 | 3.37 | 2.41 | 2.93 | 1.01 | 3.11 | 2.13 | 1.77 | 1.52 |
| 2 | 3.00 | 2.78 | 2.00 | 1.66 | 2.74 | 2.47 | 1.70 | 1.66 |
| 3 | 2.74 | 2.63 | 2.00 | 1.64 | 2.47 | 2.21 | 1.38 | 1.87 |
| 4 | 3.00 | 2.26 | 2.44 | 1.13 | 2.30 | 1.64 | 1.79 | 1.13 |
| 5 | 3.74 | 2.41 | 2.07 | 1.40 | 3.19 | 2.11 | 1.34 | 1.74 |
| 6 | 3.44 | 2.63 | 1.96 | 1.66 | 3.15 | 2.21 | 1.60 | 1.67 |
| 7 | 3.22 | 1.48 | 2.19 | 0.73 | 3.09 | 1.51 | 1.47 | 1.17 |
| 8 | 3.37 | 2.44 | 2.48 | 1.15 | 3.04 | 1.79 | 1.72 | 1.28 |
| 9 | 3.70 | 2.78 | 1.63 | 1.96 | 3.77 | 2.30 | 1.28 | 1.97 |
| 10 | 2.74 | 2.89 | 1.89 | 2.27 | 2.98 | 2.45 | 1.40 | 2.12 |
| MEAN | 3.23 | 2.47 | 2.16 | 1.46 | 2.98 | 2.08 | 1.54 | 1.61 |

Table 5. 3: Experimental Data of the Questionnaires

Immediately following the analysis of the raw experimental data, we observed some noteworthy results: both groups showed high consistency in terms of their correct answers (mean values are 2.47 and 2.08), and the subjects of the first group needed more time (2.16 units) to fulfill the task of replying to the research questions compared to the subjects of the second group (1.54 units). A valid hypothesis supporting this variance in the mean values of time elapsed is, that the first group consisted of BSc students only (27 subjects), while the second group also contained 19 MSc students which are specialized in Business Computing (28 BSc subjects, 19 MSc subjects). In order to clarify this hypothesis, the 27 pre-graduate subjects of the first group have limited experience and capabilities regarding process modeling and BPR when compared directly to the MSc students. Therefore, the mean efficiency of the second group (1.61) has a slightly higher value than the mean efficiency exhibited by the first group of subjects (1.46). Lastly in terms of their subjective opinion on plasticity, the mean values display a slight variance as well (3.23 and 2.98 respectively). This slight variance is rendered to the MSc students that participated in the second group, and is justified by their increased experience in process modelling and redesign.

## 5.2 Experimental Results

### Correlation Analysis

Pearson correlation method is widely used to interpret/justify a relationship between quantitative, categorical variables and numerical traits within datasets. **Pearson's correlation coefficient is a measure of strength of the linear relationship between two such variables ,** i.e. higher values indicate stronger relationship between the corresponding variables [112]. The correlation analysis conclusions that derived from the final experimental data concerning plasticity (PL), are expressed as follows. Particularly, these correlations were observed, between plasticity and some of the elected metrics **<u>(1 and 2 stand for the respective group)</u>**: **(a) TS** (-0.385, 0.272) in (1), **(b) NSFG** (-0.409, 0.241) in (1), **(c) CLA** (-0.624, 0.054) in (1), **(d) TNG** (-0.435, 0.209) in (1) and **(e) CFC** (0.373, 0.289) in (2), **(f) AGD** (0.622, 0.055) in (2).

The correlations observed between correct answers (CA) and a subset of the selected metrics are **<u>(1 and 2 stand for the respective group)</u>**: **(a) NoAJS** (0.374, 0.286) in (1), **(b) AGD** (0.493, 0.148) in (2), **(c) CFC** (0.525, 0.120) in (1) and (0.541,0.107) in (2) , **(d) NSFG** (0.475, 0.165) in (1) and (0.508, 0.134) in (2), **(e) CLA** (0.436, 0.208) in (1) and (0.568, 0.087) in (2), **(f) TNG** (0.437, 0.207) in (1) and (0.485,0.156) in (2), **(g) TS** (0.378, 0.282) in (2), **(h) Sequentiality (Ξ)** (-0.412, 0.236) in (1) and (-0.648, 0.043) in (2).

We also detected the following correlations between time elapsed (T) and the majority of the chosen measures <u>(1 and 2 stand for the respective group)</u>: **(a) NoA** (-0.421, 0.226) in (1) and (-0.386, 0.271) in (2), **(b) NoAJS** (-0.426, 0.219) in (1) and (-0.398, 0.254) in (2), **(c) TS** (-0.370, 0.292) in (1) and (-0.385, 0.272) in (2), **(d) CFC** (-0.550, 0.100) in (1) and (-0.425, 0.221) in (2), **(e) NSFG** (-0.422, 0.225) in (1) and (-0.380, 0.279) in (2), **(f) CLA** (-0.354, 0.315) in (1) and (-0.450, 0.192) in (2), **(g) TNG** (-0.406, 0.244) in (1) and (-0.390, 0.266) in (2), **(h) Sequentiality (Ξ)** (0.385, 0.272) in (1) and (0.396, 0.257) in (2), **(i) AGD** (-0.395, 0.259) in (2).

Regarding the correlations between efficiency (EF) and the group of our elected metrics, we discovered the following <u>(1 and 2 stand for the respective group)</u>: **(a) NoA** (0.603, 0.065) in (1) and (0.459, 0.182) in (2), **(b) NoAJS** (0.665, 0.036) in (1) and (0.553, 0.097) in (2), **(c) AGD** (0.488, 0.152) in (2), **(d) TS** (0.636, 0.048) in (1) and (0.567,0.087) in (2), **(e) CFC** (0.774, 0.009) in (1) and (0.673, 0.033) in (2), **(f) NSFG** (0.731, 0.016) in (1) and (0.661, 0.038) in (2), **(g) CLA** (0.637, 0.048) in (1) and (0.726, 0.017) in (2), **(h) TNG** (0.708, 0.022) in (1) and (0.648, 0.043) in (2), **(i) Sequentiality (Ξ)** (-0.551, 0.099) in (1) and (-0.684, 0.029) in (2).

<u>Therefore, we have discovered some evidence that our selected metrics correlate to the model of plasticity.</u>

## Binary Regression Analysis & Application of the Bender Method

In order to discover the threshold values that have the capacity to characterize the plasticity of BPMN models, we utilized the experimental data of the two previously-defined experiments. The implementation of the Bender method (Ch.3.4) relies on binary logistic regression (Ch. 3.4) to assess if there is a strong relationship between metrics and the plasticity of process models. In our experiments, the continuous risk factor is represented by the values of the different metrics in each of the 10 BPMN models and the binary response variable would be the average efficiency of plasticity. Because in our experiments the efficiency of plasticity is not a binary variable, we converted it into a bicameral one by assigning a value of 1 when it was higher than the median and 0 regarding the case it was lower [113]. Table 5.4 displays the alpha and beta values (α, β) of the logistic regression formula for both experiments, including their significance.

| | Experiment 1 | | | Experiment 2 | | |
|---|---|---|---|---|---|---|
| | alpha | beta | Sig. | alpha | beta | Sig. |
| NoA | 1.737 | -0.056 | 0.512 | 0.855 | -0.029 | 0.722 |
| NoAJS | 2.052 | -0.058 | 0.318 | 1.084 | -0.034 | 0.515 |
| AGD | 3.003 | -0.726 | 0.611 | -6.267 | 2.219 | 0.562 |
| TS | 1.325 | -0.378 | 0.294 | 0.718 | -0.276 | 0.389 |
| CFC | 2.153 | -0.197 | 0.224 | 0.844 | -0.070 | 0.577 |
| NSFA | -1.004 | 0.215 | 0.319 | -0.955 | 0.152 | 0.432 |
| NSFG | 2.429 | -0.239 | 0.373 | 1.052 | -0.094 | 0.384 |
| CLA | 10.548 | -5.502 | 0.202 | 4.451 | -2.336 | 0.189 |
| TNG | 2.413 | -0.383 | 0.407 | 1.052 | -0.147 | 0.371 |
| Ξ | -1302.172 | 3349.637 | 0.984 | -0.334 | 1.487 | 0.629 |

Table 5. 4: Binary Logistic Coefficients & Significance Values

The Bender method delineates a value of an acceptable risk level (or VARL), given by the p0 probability. In detail, this means that a metric value smaller than VARL signifies that the risk of a model being non-plastic is lower than p0 [3]. VARL can be computed by utilizing the formula portrayed in Fig.40 (Ch. 3.4).

Therefore, we established the following p0 values in order to create disparate levels of plasticity:

- Level 1: 10% probability of acknowledging the model as efficiently plastic.
- Level 2: 30% probability of acknowledging the model as efficiently plastic.
- Level 3: 50% probability of acknowledging the model as efficiently plastic.
- Level 4: 70% probability of acknowledging the model as efficiently plastic.
- Level 5: 90% probability of acknowledging the model as efficiently plastic.

For both experiments, we acquired disparate threshold values presented in Table 5.5.

| Level | NoA | | NoAJS | | AGD | | TS | | CFC | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 |
| 1 | 70 | 105 | 74 | 97 | 7.166 | 1.834 | 9 | 11 | 22 | 43 |
| 2 | 46 | 59 | 50 | 57 | 5.305 | 2.443 | 6 | 6 | 15 | 24 |
| 3 | 31 | 30 | 36 | 32 | 4.138 | 2.824 | 4 | 3 | 11 | 12 |
| 4 | 16 | 0 | 21 | 7 | 2.970 | 3.206 | 1 | 0 | 7 | 0 |
| 5 | -8 | -46 | -3 | -33 | 1.110 | 3.815 | -2 | -5 | 0 | -19 |
| **Level** | **NSFA** | | **NSFG** | | **CLA** | | **TNG** | | **Sequentiality (Ξ)** | |
| | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 | Exp1 | Exp2 |
| 1 | -6 | -8 | 19 | 35 | 2.316 | 2.846 | 12 | 22 | 0.388 | -1.253 |
| 2 | 1 | 1 | 14 | 20 | 2.071 | 2.268 | 9 | 13 | 0.388 | -0.345 |
| 3 | 5 | 6 | 10 | 11 | 1.917 | 1.906 | 6 | 7 | 0.389 | 0.225 |
| 4 | 9 | 12 | 7 | 2 | 1.763 | 1.543 | 4 | 1 | 0.389 | 0.794 |
| 5 | 15 | 21 | 1 | -12 | 1.518 | 0.965 | 1 | -8 | 0.389 | 1.702 |

Table 5. 5: Initial Threshold Values

The values depicted in the Table 5.5 can be translated in the following manner: if the TS of a model is between 0 and 1, NSFA is between 9 and 12, NSFG is between 2 and 7, CLA is between 1.543 and 1.763 and TNG is between 1 and 4 then the probability of acknowledging the model efficiently plastic, regarding the applicability of the PAR heuristic, is 70%. However, some of the thresholds extracted in Table 5.5 lack consistency, judging by the facts that they display negative or out of limit values (e.g., NoA, Ξ). In order to resolve this problem, we evaluated the significance of every logistic regression performed. A significance level of 50% or 0.500 signifies a 50% risk of deducing that an association exists when in fact there is no actual association. The Sig. parameter in Table 5.4 highlights the relationship between every complexity metric and the efficiency of plasticity. **Therefore, we state the assumption that a Sig. value below 0.500 is deemed satisfactory**. Based on this assumption, we observe that the **NoA, AGD and Ξ metrics are not significant in both experiments** and the acquired threshold values of **NoAJS and CFC are not significant in Exp2** (the calculated Sig. values and the resulting thresholds of these metrics, are indicated in red font). As a direct result, we believe that the resulting threshold values of NoA, AGD and Ξ measures are not significant from a statistical point-of-view, and are excluded from the study. The same applies to the threshold values of NoAJS and CFC in Exp2. The final threshold values can be viewed in Table 5.6, with their values being the computed means, except for the NoAJS and CFC metrics where the values were taken from the Exp1 only. In order to make the classification of models even more clear, we organized the metrics using different levels of plasticity that can be viewed in Table 5.6.

| Metric | Plasticity | | | | |
|---|---|---|---|---|---|
| | Level 1: Very inefficient | Level 2: Rather inefficient | Level 3: Moderately efficient | Level 4: Rather efficient | Level 5: Very efficient |
| NoAJS | 74 | 50 | 36 | 21 | 0 |
| TS | 10 | 6 | 3 | 1 | 0 |
| CFC | 22 | 15 | 11 | 7 | 0 |
| NSFA | 0 | 1 | 6 | 11 | 18 |
| NSFG | 27 | 17 | 11 | 5 | 0 |
| CLA | 2.581 | 2.170 | 1.911 | 1.653 | 1.241 |
| TNG | 17 | 11 | 7 | 3 | 0 |

Table 5. 6: Final Threshold Values

<u>Regarding Table 5.6, we applied the two following mathematical corrections:</u>

- **If the lower limit of a threshold was negative, we equalized it to zero.**
  **And**
- **When the computed mean value of a threshold was *.500, we rounded it up to the immediately next integer value, in agreement with the metrics that unequivocally produce integer final values only (i.e., TS, NSFA, NoAJS, etc.).**

## Complexity metrics threshold values diagrams

Figures 41 through 47 illustrate the evolution of the final threshold values (y-axis) in relation to the probability p0% of a model to be efficiently plastic (x-axis), for the seven (7) complexity measures respectively.

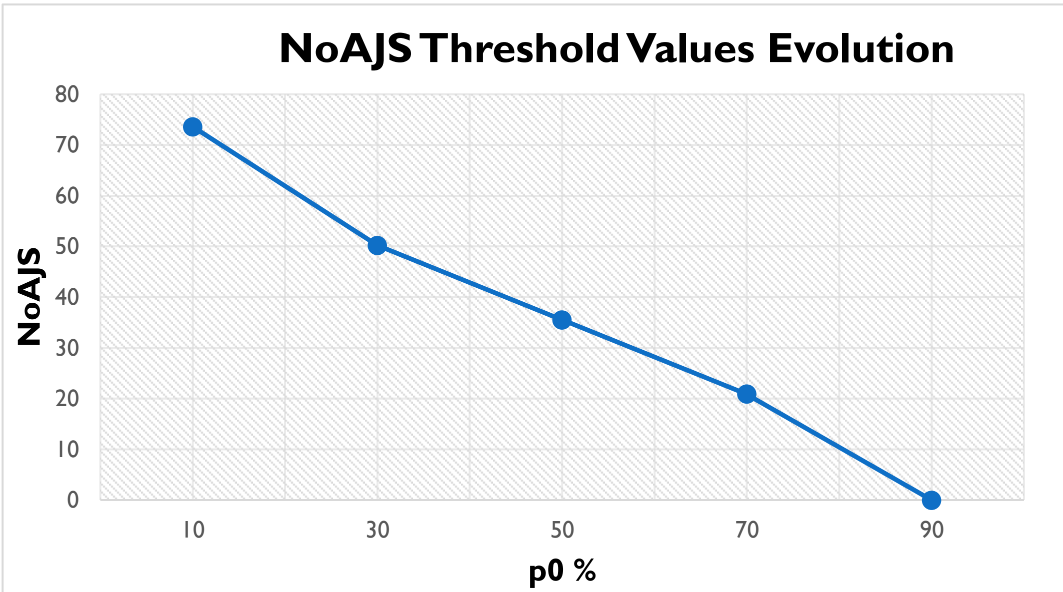


Figure 42: NoAJS Threshold Values evolution, in relation to p0%

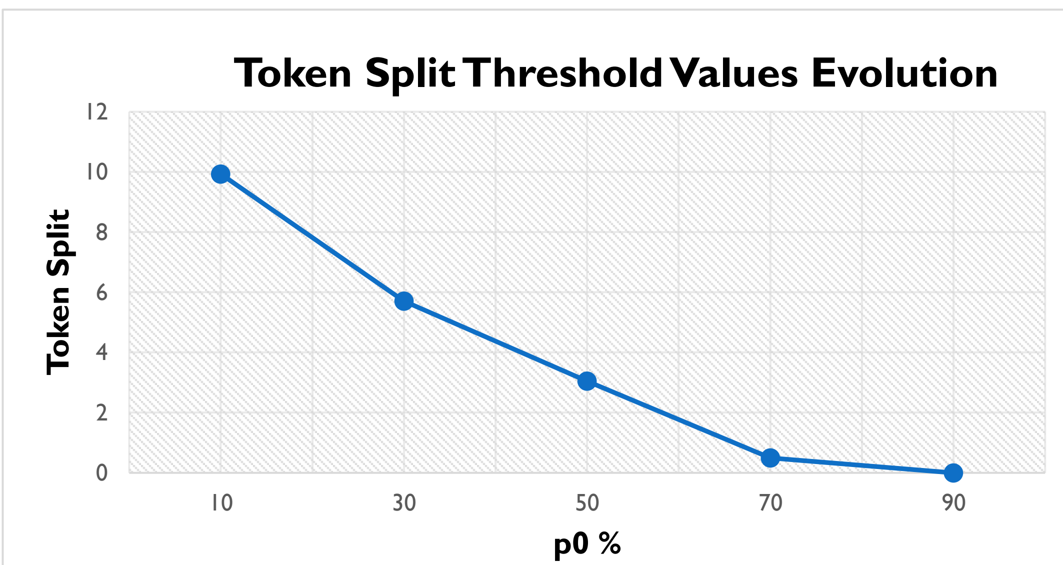


Figure 43: Token Split Threshold Values evolution, in relation to p0%

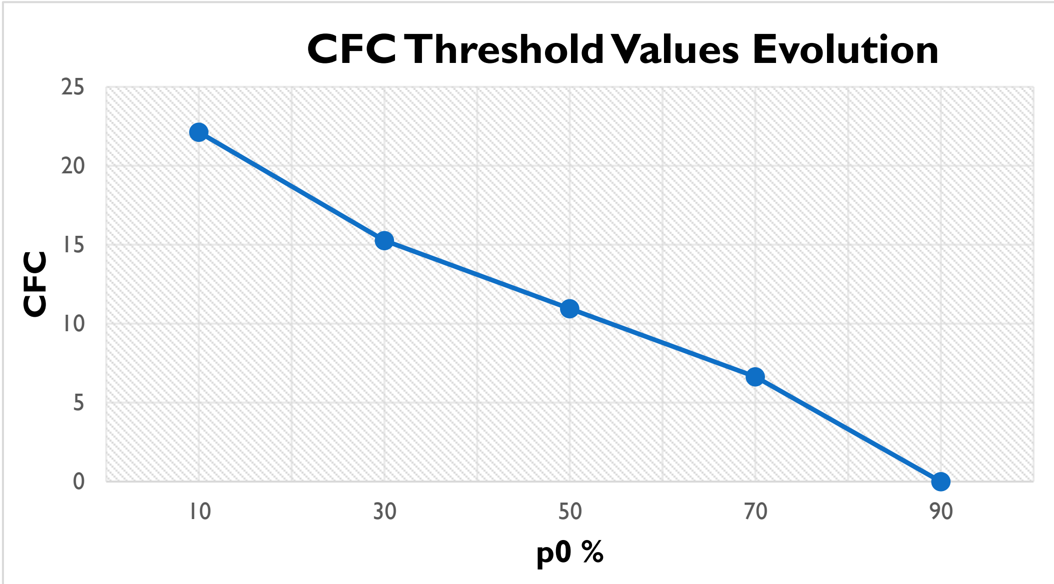


Figure 44: CFC Threshold Values evolution, in relation to p0%

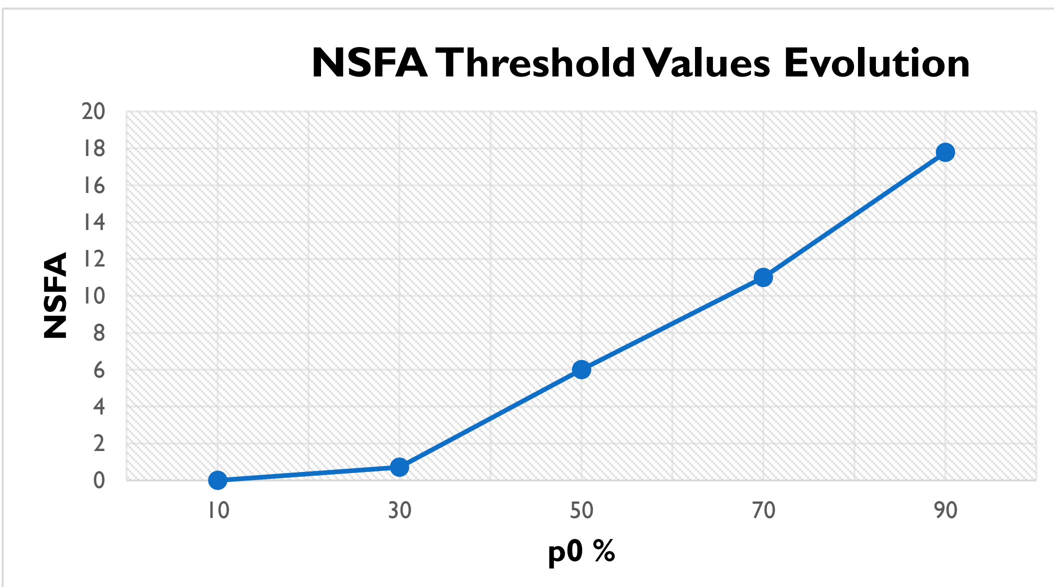


Figure 45: NSFA Threshold Values evolution, in relation to p0%

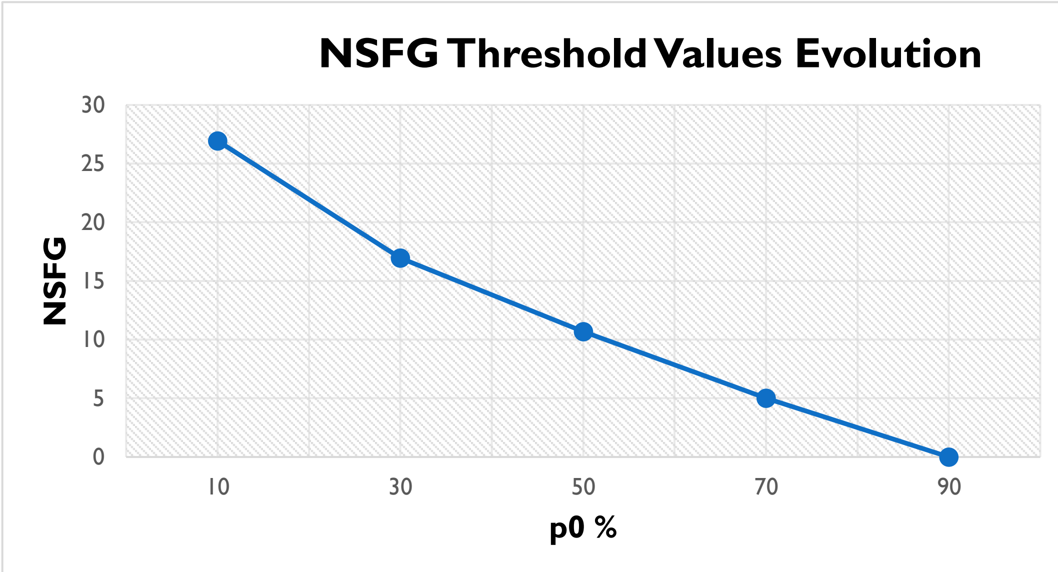


Figure 46: NSFG Threshold Values evolution, in relation to p0%

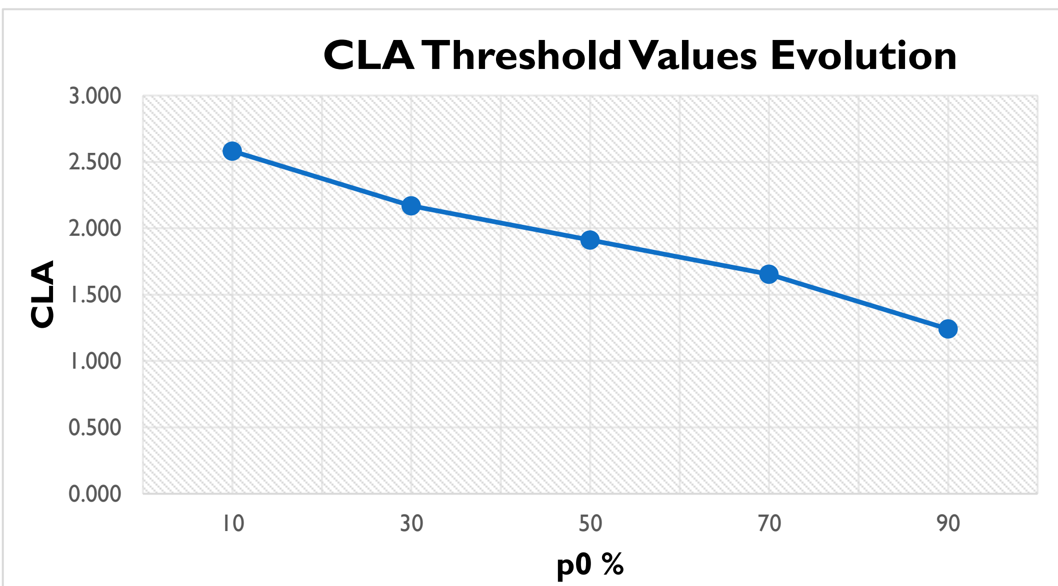


Figure 47: CLA Threshold Values evolution, in relation to p0%

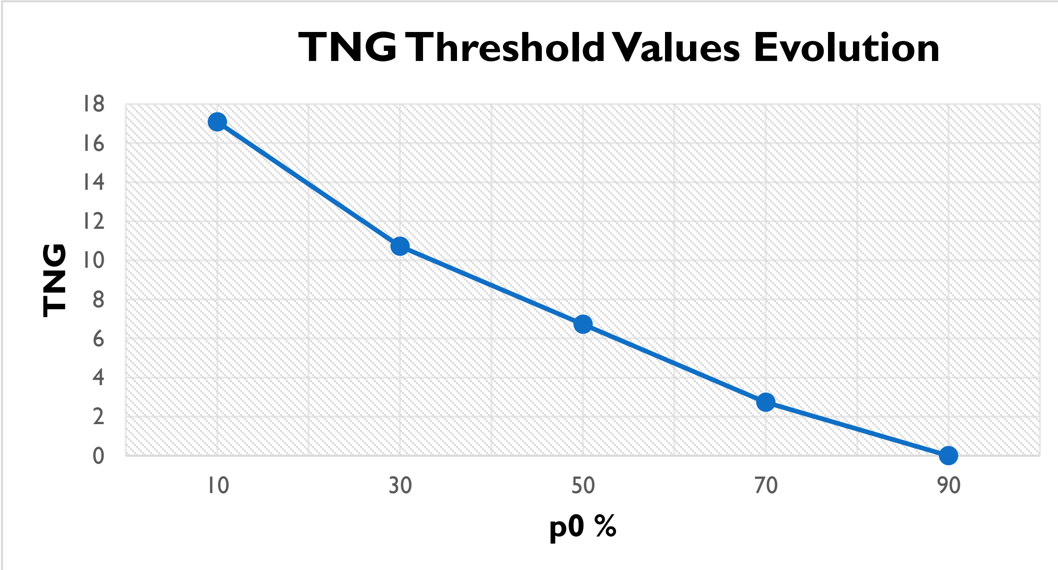


Figure 48: TNG Threshold Values evolution, in relation to p0%

The data presented in Table 5.6 can be interpreted in the following manner: if NoAJS has a value lower than 21 and closer to zero, CLA is 1.241 or NSFA is 18, then the model is deemed as "very efficient" in terms of its plasticity. On the other hand, if NoAJS is equal to 74, NSFG is 27 and CFC is 22 then the model is characterized as "very inefficient" regarding its plasticity.

## 5.3 Chapter Summary

The 5th Chapter of our thesis, is focused on the experiments that were carried out in order to prove which of the initial 13 complexity metrics affect the quality trait that refers directly to the ability of a model to be easily transformed or reshaped, defined as Plasticity throughout our thesis [3]. We began our analysis by selecting a subset of 13 complexity metrics, from the complete list of complexity metrics (Table 3.1) [10], that are straightforwardly related to the PAR heuristic. The next step was to set the hypothetical correlations between every metric and the model of Plasticity (Subsection 5.1). The subsections 5.2,5.3 include all the required information regarding the design of the aforementioned experiments, as well as all the statistical and computed data we produced in order to perform all the mathematical methods (subsection 5.3) required to obtain threshold values for the subset of the 13 complexity measures initially selected. Ultimately, we were able to produce relevant threshold values for 7 of the 13 measures that were originally elected to participate in our research.

# 6.Validation of Plasticity

In this chapter we assess the plasticity of four distinct process models from literature. In order to achieve the desired validation for the model of Plasticity we opted to select four process models that exhibit distinct overall complexities and have different sizes in terms of the activities they contain. As a first step we compared the two rather small process models and later on we compared the two moderately sized process models. In both scenarios the compared models exhibited different levels of overall complexity, varying from low to high.

## 6.1 Bug Reporting Process

The first candidate model (Fig. 48) is a bug reporting process ,developed by the Link Consulting Company [114]. This specific model is rather small in size and exhibits low overall complexity. We hypothesize that certain tasks are constrained in an explicit manner based on the execution logic, and specifically the explicit constraints are the following [3]:

- *init* (Report a bug),
- *chain_precedence* (Create tasks, associate tasks to Developer)
- *precedence* (Create tests, Execute Tests)
- *last* (Execute Tests)

The implicit constraints are the following [3]:

- *coexistence* (Create tests, Create tasks)
- *coexistence* (Create tests, Associate tasks to Developer)
- *coexistence* (Create tests, Work on related tasks)
- *coexistence* (Create tests, prepare work done for testing)

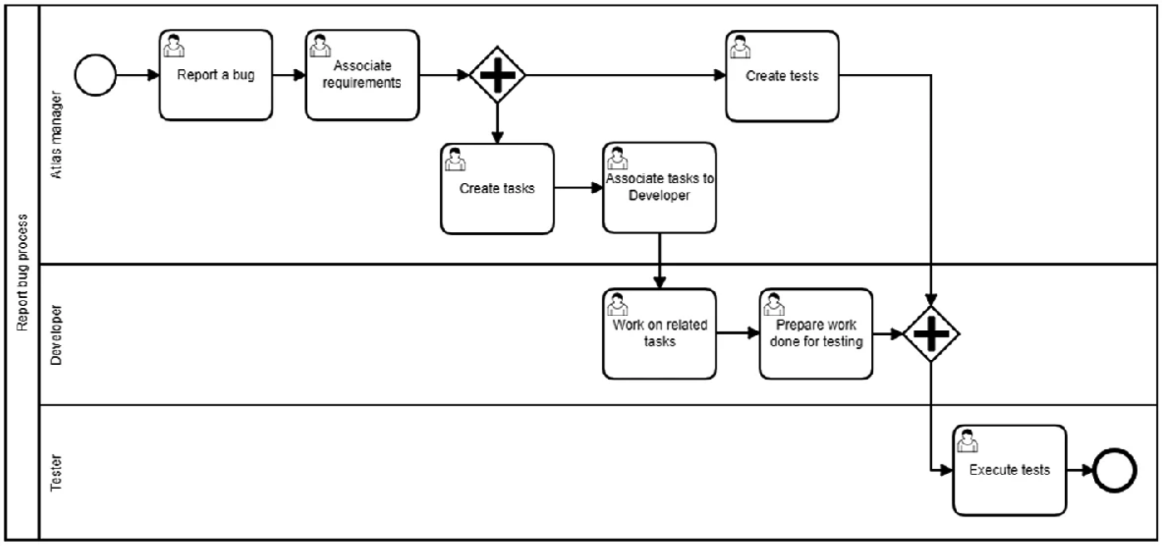


Figure 49: Bug Reporting Process, Link Consulting Company [114]

The computed values of the complexity metrics are: NoAJS=10, CLA= 2, CFC=1, NSFA=4, NSFG=3, TNG=2, TS=1. In order to form a concrete evaluation regarding this model's plasticity, we utilized the threshold values from the Table 5.6:

- **NoAJS=10**, there is approximately an 80% probability that the model will be plastic (rather to very efficient).
- **CLA=2**, there is approximately a 48% probability that the model will plastic (rather inefficient to moderately efficient).
- **CFC=1**, there is approximately an 88% probability that the model will plastic (rather to very efficient).
- **NSFA=4**, there is approximately a 42% probability that the model will be plastic (rather inefficient to moderately efficient).
- **NSFG= 3**, there is approximately an 80% probability that the model will be plastic (rather to very efficient).
- **TNG=2**, there is approximately a 74% probability that the model will be plastic (rather to very efficient).
- **TS=1**, there is a 70% probability that the model will be plastic (rather efficient).

## 6.2 Complaint Handling Process

The second candidate model (Fig.49), is the Complaint Handling process [115]. This model has a comparable size to the previous one (Fig.48), but exhibits higher overall complexity. In order to extract the explicit constraints, we follow the same procedure as we did previously (Fig.48) [3]:

- *init* (Call registration)
- *precedence* (External referral with form B4, Telephone Confirmation to external party)
- *chain_precedence* (Contact complainant, Archiving System1)

The implicit constraints are the following [3]:

- *xor_existence* (External referral with form B4, Internal referral with form B2)
- *xor_existence* (External referral with form B4, Complaint analysis)
- *xor_existence* (External referral with form B4, Contact complainant)
- *xor_existence* (External referral with form B4, Archiving system1)
- *xor_existence* (Internal referral with form B2, Complaint analysis)
- *xor_existence* (Internal referral with form B2, Contact complainant)
- *xor_existence* (Internal referral with form B2, Archiving system1)

The activities labeled as: "Telephone confirmation to external party", "Archiving system2" and "Incident agenda" are involved in several implicit constraints.

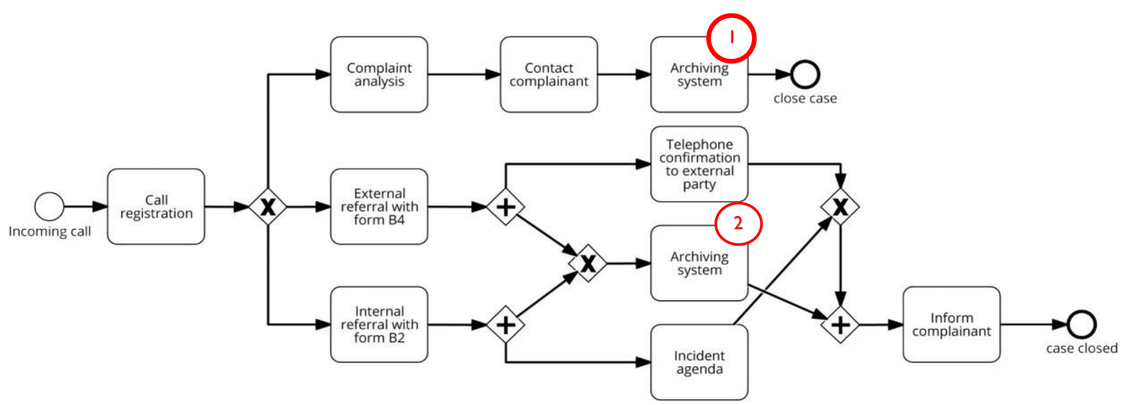


Figure 50: Complaint Handling Process [115]

The calculated values of the metrics are: NoAJS=16, CLA=5, CFC=5, NSFA=2, NSFG=10, TNG=6, TS= 3. Assessing this model's plasticity was achieved by using the threshold values presented in Table 5.6:

- **NoAJS=16**, there is approximately a 73% probability that the model will be plastic (moderately to rather efficient).

- **CLA=5**, there is a probability smaller than 10% that the model will be plastic (very inefficient).
- **CFC=5**, there is approximately a 75% probability that the model will be plastic (moderately to rather efficient).
- **NSFA=2**, there is approximately a 33% probability that the model will be plastic (rather inefficient to moderately efficient).
- **NSFG=10**, there is approximately a 52% probability that the model will be plastic (moderately to rather efficient).
- **TNG=6**, there is approximately a 53% probability that the model will be plastic (moderately to rather efficient).
- **TS=3**, there is a 50% probability that the model will plastic (moderately efficient).

## 6.3 Pre-takeoff Process

The third candidate model (Fig.50) is the pre-takeoff process [116]. This particular model is considered moderate in terms of its size and exhibits a relatively high overall complexity. We hypothesize that certain activities are constrained explicitly, based on the model's execution logic:

- *init* (Check Weather1)
- *precedence* (Check Weather2, Perform Preflight Inspection)
- *chain_precedence* (Contact Tower, Get Take-off Clearance)
- *last* (Take-off Airplane)

The implicit constraints are the following:

- *xor_existence* (Move to Repair Station, Tow to Repair Station)
- *xor_existence* (Move to Repair Station, Get Mechanician)
- *xor_existence* (Announce Taxiing, Contact Ground)
- *xor_existence* (Announce Taxiing, Get Taxi Clearance)
- *xor_existence* (Announce Take-off Intentions, Contact Tower)
- *xor_existence* (Announce Take-off Intentions, Get Take-off Clearance)
- *xor_existence* (File Flightplan)

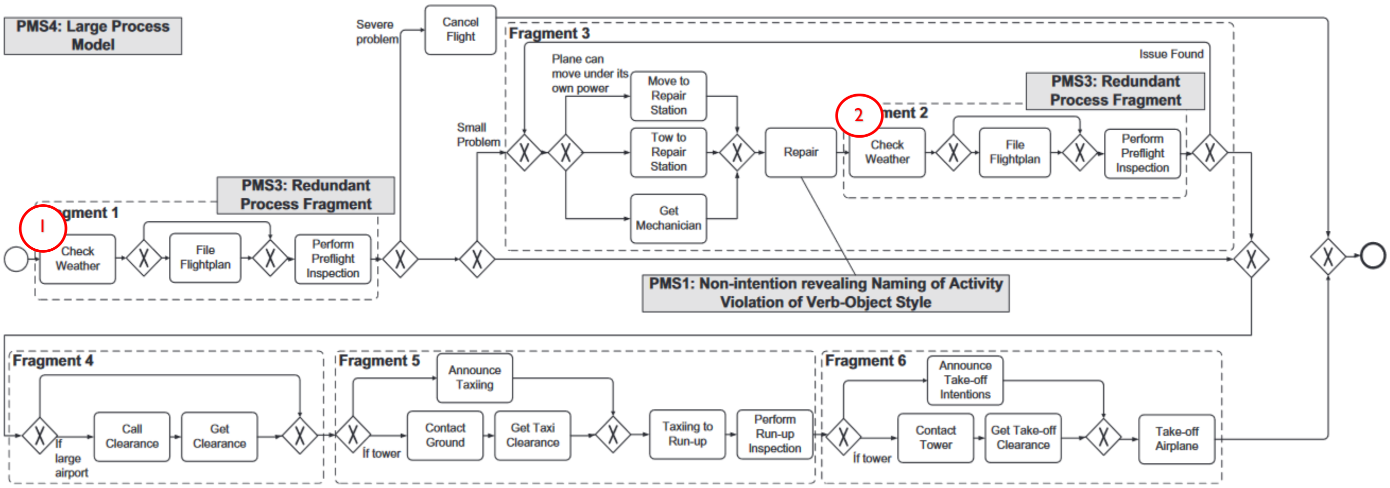


Figure 51: Pre takeoff process [116]

The computed values of the metrics are: NoAJS=40, CLA=5.5, CFC=17, NSFA=4, NSFG=26, TNG=18, TS=0. Evaluating the plasticity of the model presented in Fig.50 was achieved by using the threshold values presented in Table 5.6:

- **NoAJS=40**, there is approximately a 44% probability that the model will be plastic (very to rather inefficient).
- **CLA=5.5**, there is a probability smaller than 10% that the model will be plastic (very inefficient).
- **CFC=17**, there is approximately a 22% probability that the model will be plastic (very to rather inefficient).
- **NSFA=4**, there is approximately a 42% probability that the model will be plastic (rather inefficient to moderately efficient).
- **NSFG=26**, there is approximately a 12% probability that the model will be plastic (very inefficient).
- **TNG=18**, there is a probability less than 10% that the model will be plastic (very inefficient).
- **TS=0**, there is a 90% probability that the model will plastic (very efficient).

## 6.4 User performed query on the Google search engine

The fourth candidate model (Fig.51) is the user performed query on the Google search engine [117]. Regarding its size this model is deemed moderate, while exhibiting low to medium overall complexity. Once again, we shall extract the explicitly constrained activities relying on the execution logic of the model:

- *init* (Connect to Google)
- *precedence* (Complete query, Display results page)
- *precedence* (Update the cookie3, Visualize results)

In a similar manner as before, the implicit constraints are the following:

- *xor_existence* (Read the cookie, Set user's preferences from browser info)
- *xor_existence* (Retrieve user's preferences, Set user's preferences from browser info)
- *xor_existence* (Send cookie information)
- *coexistence* (Update the log, Update the cookie1)
- *coexistence* (Save link information, Update the cookie2)
- *coexistence* (Update the cookie4, Open the selected link)

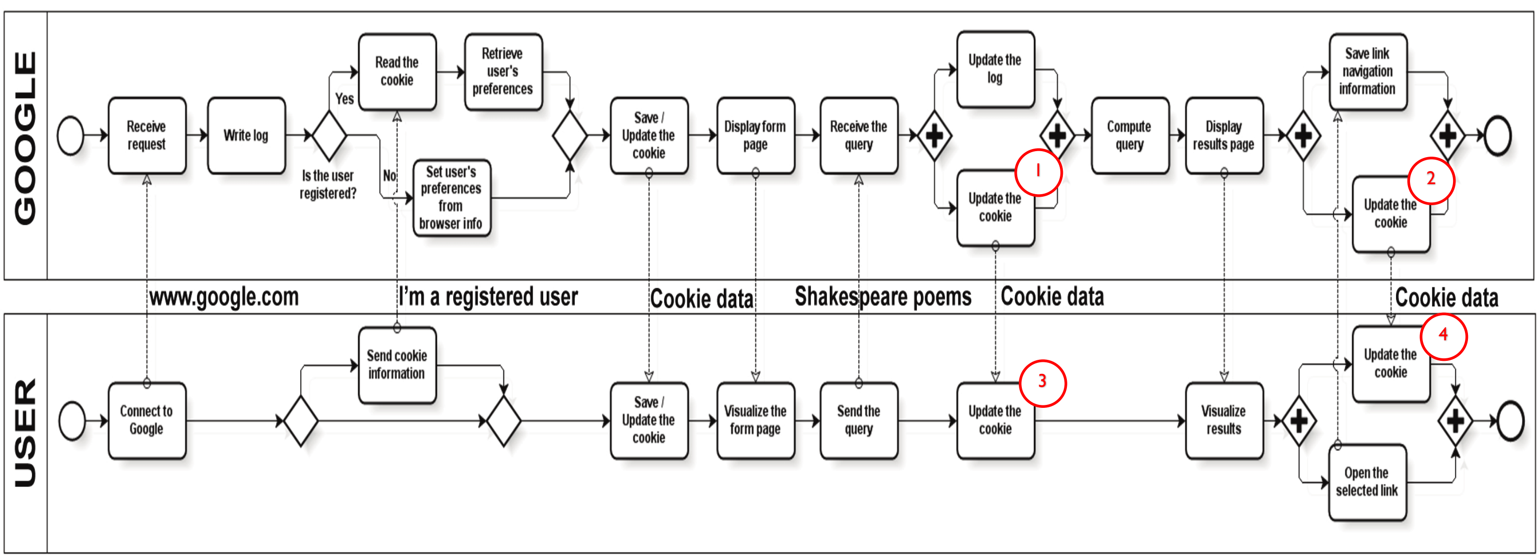


Figure 52: User performed query on the Google search engine [117]

The computed values of the metrics are: NoAJS=33, CLA=2.55, CFC=7, NSFA=9, NSFG=11, TNG=10, TS=5.

Evaluating the plasticity of the model presented in Fig.50 was achieved by using the threshold values presented in Table .6:

- **NoAJS=33**, there is approximately a 53% probability that the model will be plastic (moderately to rather efficient).
- **CLA=2.55**, there is approximately an 11% probability that the model will be plastic (very to rather inefficient).
- **CFC=7**, there is a 70% probability that the model will be plastic (rather efficient).
- **NSFA=9**, there is approximately a 63% probability that the model will be plastic (moderately to rather efficient).
- **NSFG=11**, there is a 50% probability that the model will be plastic (moderately efficient).
- **TNG=10**, there is approximately a 34% probability that the model will be plastic (very to rather inefficient).
- **TS=5**, there is approximately a 35% probability that the model will plastic (rather inefficient to moderately efficient).

## 6.5 Results Discussion

At this point, we shall briefly discuss the efficiency of plasticity for these four models. Starting with the first two, although similar in size they exhibit a substantial difference in terms of their respective plasticity and ultimately its efficiency. Despite its small size, the first model has 3 sequence flows that begin from gateways, this value characterizes the model as very efficient in terms of its plasticity, and 6 out of its 8 activities in total are set in a sequential manner. The only values that could possibly dismay process modelers to apply the PAR heuristic, would be those of the CLA and NSFA metrics that render the model as rather inefficient to moderately efficient with 42% and 48% probabilities respectively, that the model would be plastic. The second case study has similar size to the first model but exhibits high overall complexity. The model is highly constrained (80% of its activities) with only 3 activities set sequentially. Even though 5 out of the 7 metrics characterize the model as moderately efficient at least, the CLA and NSFA measures typify the model as very inefficient and rather inefficient to moderately efficient with a lower than 10% and 33% probabilities accordingly. Looking at the bigger picture, this entails that the second model is considered rather inefficient to moderately efficient with a less than 50% probability (mean value) for it to be plastic, a fact that should dissuade modelers from initiating redesign endeavors by applying the PAR best practice on this specific model.

Moving on to the last two models, both of them are considered moderate in terms of their respective size with a similar number of activities, while having different overall complexities. Given its high overall complexity (18 gateways in total), the third model is highly constrained since only 4 of its total activities are set in a sequential manner. Besides the fact that only the TokenSplit (TS) and NSFA metrics characterize the model as very efficient and rather inefficient to moderately efficient with 90% and 42% probabilities accordingly, the remaining five measures typify the model as very to rather inefficient. In turn, this outlines the fact that this model has a relatively low probability (32.8%) to be plastic and therefore process modelers should not attempt to redesign it. In regard of the fourth model, it is less constrained with 14 activities set sequentially while having a lower total number of gateways when compared to the third model. The two metrics that characterize the model as very to rather inefficient (regarding its plasticity) are the CLA and TNG, with approximately 11% and 34% probabilities accordingly for the model to be efficiently plastic, while the TokenSplit (TS) metric describes the model as rather to moderately efficient with approximately a 35% probability. The remaining 4 out of the 7 measures characterize the model as moderately efficient at least (in some occasions as rather efficient), a fact which entails that this model is a viable candidate to be redesigned by applying the PAR heuristic.

# 7.Discussion, Conclusions & Future Work

This chapter concludes our thesis, by summarizing the primary remarks and the research contributions of the application of our presented framework for the model of Plasticity. Therefore, the limitations of our research are provided along with suggestions for future work, that could expand the validity of the Plasticity concept and its relation to other redesign heuristics in the BPR domain.

## 7.1 Main Observations

This subsection encapsulates and highlights the main remarks and what was reviewed in detail in the previous chapters.

Chapter 2 provided a thorough overview of all the redesign approaches available currently, in the existing literature. These methods were classified according to their definitions in order to portray their respective natures accurately, with the help of "The Redesign Orbit", by Dumas et.al. [4]. Given the fact that each method has its own specifics, traits and methodology that differentiate it from the rest of the approaches, the distinction between them needed to be as detailed as possible. The chapter concluded with an analysis of the Transformational redesign methods, which by definition are substantially different from the Transactional methods.

Chapter 3 highlighted the key concepts that hold a significant role in this thesis. A detailed examination of the current literature was conducted, beginning with the 29 best practices included in HPR method. The model of Plasticity as defined by Tsakalidis et.al. [3], complexity metrics and threshold evaluation mathematical and/or statistical methods were assessed fully in the consecutive subsections (3.2-3.4) of the 3rd chapter of our thesis.

Chapter 4 signified the necessary steps taken to visualize and create a comprehensive framework for the model of Plasticity. The election of an appropriate redesign method that set us in the right course to achieve our experimental aim and objectives was the first step towards the establishment of our framework. Given the fact that as a redesign approach we opted to select HPR, choosing the PAR heuristic was the next logical step. An additional reason behind our choice was that this thesis is partially an effort to expand the work of Tsakalidis et.al. [3], to augment the validity of the Plasticity model and its correlation to other redesign heuristics besides RESEQ. In order to achieve our primary goal, selecting an appropriate subset of complexity metrics that relate to the PAR heuristic was the next stage towards the completion of our framework, which in our case this subset consisted of 13 different complexity model measures. The final step of the 4$^{th}$ Chapter was to elect a threshold extraction method that had the capacity to produce reliable and relevant threshold values for these metrics, and was best suited for the variables' nature included in our experiments.

Chapter 5 entailed all the related work regarding the experiments that were carried out, for the purposes of this thesis. The first step was a detailed review of the internal metrics selected and the hypothetical correlations set that we aimed to prove later on (subsection 5.3). Followed by a comprehensive analysis of the experiments' design, in terms of the total number of subjects, the form of the questionnaire they had to answer and the nature of the data we collected in order to perform mathematical and statistical analysis at a later stage (subsection 5.3) that eventually produced relevant threshold values for 7 complexity measures of the 13 that were initially selected.

The last chapter of this thesis, Chapter 6, concludes our research by providing the necessary validation for the model of Plasticity. Four process models were selected from literature, that in our case acted as case studies in order to assess the probability of these models to be efficiently plastic. These models were presented in the form of diagrams with the use of BPMN and their respective size varied from small to moderate (number of activities). In order to reach a concrete resolution for every model regarding its redesign capability, first we calculated the values of the 7 metrics that produced relevant threshold values for all the models. Then by using the threshold values diagrams for each metric (subsection 5.3) we estimated the probability of every model and whether it is efficiently/inefficiently plastic. Therefore, a brief discussion on the results of each model's ability to be redesigned by applying the PAR heuristic concludes the 6$^{th}$ Chapter.

The findings of chapters 2,3 were put together in chapter 4 where our proposed framework for Plasticity, is introduced for the first time. The aforementioned experiments (Ch.5) were designed in conjunction with this framework, to fulfill the research aim and objectives set in the 1$^{st}$ chapter of our thesis. Four process models (case studies) from the relevant literature were put forward to demonstrate how our framework assesses the plasticity of process models, namely how it computes the probability of a model regarding the efficiency (or inefficiency) of its plasticity. The primary takeaway of this framework is that it will provide modelers and/or redesigners with some concrete guidance, before they initiate any redesign endeavors on process models by applying the PAR heuristic.

## 7.2 Research Contributions & Future Work

Our proposed framework for the model of Plasticity -as presented in this thesis- aims to introduce a comprehensive approach towards the assessment of process models and their capacity to be redesigned prior to the implementation of the PAR heuristic. Since it was stated earlier on numerous occasions, our research also serves as a means to extend the work of Tsakalidis et.al. [3] and in a larger scope as well by assisting with the establishment of the concept of Plasticity in the BPR domain. Given the fact that the experiments in [3] resulted in obtaining threshold values for 6 complexity metrics, 3 of which coincide with the subset that produced relevant threshold values in our research (CLA,CFC and NSFA metrics), it is not without reason to admit that potentially, a holistic and cumulative approach may be achievable. By carrying out additional experiments with a larger number of subjects that have different backgrounds, for the same (RESEQ, PAR) and/or additional heuristics, in order to prove whether there is a potential relationship between the untested heuristics and the model of Plasticity and to magnify the validity of these threshold values. Another potential idea for future work is the use of larger questionnaires that cover real-life processes. Lastly, since the BP measures related to the applicability of the PAR heuristic was not conclusive, more indicators should be explored in future research as well.

## 7.3 Limitations of research

Similarly, to the majority of every experimental project/research ever conducted, this thesis has some inherent limitations in terms of its final outcome. For some metrics we obtained different threshold values for each experiment due to the fact that the subjects had distinct backgrounds in terms of their experience and capabilities in process modelling and redesign initiatives. In this case we excluded any threshold values that proved to be statistically insignificant, while in the remaining cases we computed the mean of both values. Our initial subset of complexity metrics consisted of 13 measures 7 of which eventually produced relevant threshold values, due to low variability and significance of the logistic regression equations 6 measures had to be eliminated from the study.

## 7.4 Conclusions

This thesis presented our proposed framework for the Plasticity model; a framework to assess the capacity of process models to be redesigned, with the use of a subset of complexity metrics, by extracting threshold values for these measures and finally calculating the probability at which a model is considered as efficient or inefficient to be redesigned, prior to the application of the PAR heuristic as the main means to carry out a redesign initiative. Our findings revealed that a BP model is deemed efficiently plastic when e.g., it consists of a decreased number of gateways (less joints and splits), its activities are set in a sequential manner to the greatest extent and they are not constrained explicitly or implicitly. For instance, we deduced that if a model has NSFA value at least equal to 11, CFC value less than 5 and NSFG value less than 5, would be considered as rather efficiently plastic (70% or more probability to be considered efficient) and therefore a suitable candidate to be redesigned. This framework is intended to provide business process modelers, analysts and redesigners with a solid foundation regarding the evaluation of a model's capacity to be redesigned, prior to its actual redesign endeavor.

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