Université de Toulouse

THÈSE

En vue de l'obtention du

DOCTORAT DE L'UNIVERSITÉ DE TOULOUSE

Délivré par :
Institut National Polytechnique de Toulouse (INP Toulouse)

Discipline ou spécialité :

Systèmes industriels

Présentée et soutenue par :
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le : lundi 3 décembre 2012

Titre :

Analysis of the causes of delay in collaborative decision-making under uncertainty in pharmaceutical R&D projects

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Systèmes (EDSYS)

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To the memory of my best friend Nahal...
À la mémoire de ma meilleure copine Nahal...

به نهَال...

FONCSI
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This work was supported by the Foundation for an Industrial Safety Culture.

Ces travaux ont été soutenus par la Fondation pour une Culture de Sécurité Industrielle (FonCSI).

Acknowledgments / Remerciements

La reconnaissance est la mémoire du cœur.
Hans Christian Andersen

Le moment est enfin venu de feuilleter ces trois dernières années, savourer le souvenir des bons moments et penser à tous ceux qui ont contribué à la réalisation de ce travail et à la création d'un environnement chaleureux pour travailler.

Je tiens tout d'abord à remercier mon directeur de thèse, M. Didier Gourc. C'est à lui que je dois la chance de travailler sur ce sujet. Je le remercie de m'avoir fait confiance, d'avoir encadré ce travail et de m'avoir conseillée et encouragée tout au long de cette thèse. J'exprime ma profonde gratitude envers Mme Sophie Bougaret, co-directeur de ma thèse. J'ai eu la chance de travailler à côté d'un acteur industriel créatif et expérimenté dont je salue également les qualités humaines, ainsi que celles de sa famille : Joël, Yann et Marc Bougaret, qui m'ont chaleureusement accueillie lors de nos nombreuses réunions de travail de week-end. Je remercie également M. François Marmier, co-directeur de ma thèse, pour sa disponibilité, son énergie et ses précieux conseils.

Je voudrais adresser mes remerciements à M. René Deleuze qui, lorsqu'il était directeur de la FonCSI, m'a accordé sa confiance et m'a accueillie au sein de la fondation. Toute ma reconnaissance à Messieurs Gilles Motet et Éric Marsden pour leur soutien, pour avoir animé ce programme de recherche qui était également l'occasion de rencontrer et collaborer avec d'autres (post-)doctorants : Véronique, Nicola, Stéphanie … Merci également à Zina d'avoir géré le côté administratif de ce travail à la FonCSI.

Je remercie chaleureusement les professeurs Christophe Midler, Vincent Boly et Enrico Zio pour l'intérêt qu'ils ont témoigné à l'égard de mon travail en acceptant la charge de rapporteur. J'associe à ces remerciements M. Gilles Motet, le président du jury, Mme Sylvie Pérès-Le Scoëzec, qui m'a fait l'honneur d'avoir participé à ce jury en tant qu'acteur industriel et Mme Michèle Lalanne, qui a apporté à ce travail un nouveau point de vue, celui du sociologue.

Il y a sept personnes sans qui la réalisation de cette thèse n'aurait pas été possible ; ce sont les interviewés, qui ont généreusement accepté de m'accorder leur précieux temps. Je sais que dans le contexte extrêmement confidentiel et sensible de l'industrie pharmaceutique, il est très difficile d'accorder des interviews, particulièrement au sujet des décisions Go / No Go. Je leur en suis d'autant plus reconnaissante pour leur confiance. Je tiens à remercier M. Jean-Philippe Blanchard, Responsable du Pôle Innovation au Crédit Agricole S.A., qui nous a accordé un huitième entretien afin de commencer une étude de transposabilité de nos résultats à d'autres secteurs que celui de l'industrie pharmaceutique.

Place au GI maintenant, je commence par remercier M. Lionel Dupont, l'ex-directeur du GI, qui m'a chaleureusement accueillie au sein de son équipe et m'a toujours accordé son aide. Merci également à M. Michel Aldanondo, le nouveau directeur du GI, qui a donné une nouvelle dynamique au centre. Un immense merci à Isabelle Fournier pour son aide, sa disponibilité, sa gentillesse et les bons moments que nous avons passés à discuter de cinéma et d'expositions. Pour leur générosité, leur gentillesse et les bons moments partagés, merci aux enseignants-chercheurs du GI : Paul, Fred, Hervé, Franck, Jacques, Élise, Sabine, Matthieu, Elyes . . . Et toute ma reconnaissance à Laurent Steffan pour son aide et sa disponibilité durant ces deux dernières années. C'est avec beaucoup d'émotion que je remercie les anciens et actuels (post-)doctorants du GI (et d'autres centres) : Aurélie Ch., Marie et Paul P., Seb, Carine, Guillaume M., Hung, Thomas, Olina, Marie F., Rémi, Nico, Guillaume M.-R. . . . et la nouvelle arrivée Aurélie M., dont les rires et les pas donnent un coup de jeune au GI. De cette longue liste, je voudrais distinguer mes collègues de bureau Olfa et Aurélien, qui m'ont supportée, avec une bonne humeur, à tout moment.

Place à l'EMAC, il est très agréable de commencer la journée avec le joli sourire de Manolita à l'accueil. Je la remercie, ainsi que les filles du 'deuxième étage' : Geneu, Cathy, Françoise, Marie . . . , idem pour les filles de la bibliothèque. Un grand merci à Dolorès et Denis pour leur gentillesse, ainsi qu'à Henri Laborde. Un 'gourmand' merci à Noémie à la cafet pour m'avoir réservé ma 'chocolatine' du matin et mon brownie de l'après-midi ! J'en profite pour enchaîner avec le reste de l'équipe Compass au restaurant : Christophe, Bernard, Marie, Sandra, qui y créent une ambiance sympathique. Un 'chaleureux' merci à Jean-Claude Poussin pour le chauffage et aux gens du garage pour le vélo . . . Merci également à Abdellah.

Si la mise en page de ce document est belle, je la dois à Paul Gaborit, que je voudrais remercier pour ses coups de main en LaTeX. Mais au-delà de LaTeX, j'ai beaucoup appris à ses côtés. Sa générosité, son aide et sa disponibilité me sont extrêmement précieuses. Je tiens à remercier Andy Meehan et la société ALS Langues pour la correction de l'anglais, toujours à l'avance, ce qui est très appréciable dans le contexte de la rédaction de thèse. Je voudrais remercier Elsa Martin, doctorante à l'université de Champollion, pour nos fructueux échanges et collaborations.

Un amical remerciement à mes amis Sarah, Nesa, Vesta, Andi, Mahyar, Sia, Muriel, Aldéric, Tibo, Julien, Laurence et Alain pour l'amitié qu'ils m'ont prouvée en toute circonstance.

C'est à Javad que je réserve mon plus grand merci, pour son soutien, ses encouragements, son aide et sa patience durant toutes ces années.

Merci à toute ma famille, en particulier mes parents, je reconnais la dette de m'avoir facilité la tâche en se privant de leur fille pendant de longues années.

Enfin, je dédie ce manuscrit à celle qui aurait été si fière de me voir terminer ce travail dont elle a vu le début. Elle est toujours présente malgré sa disparition trop soudaine, ma meilleure amie Nahal.

Résumé court

Les décisions collaboratives sous incertitude dans les situations non urgentes peuvent être retardées, surtout lorsque la santé humaine et des investissements élevés sont en jeu comme c'est le cas des projets de R&D pharmaceutiques. Cette thèse étudie les causes des retards récurrents dans la prise de décision collaborative sous incertitude et les pratiques efficientes pour réduire ces retards. Pour mieux comprendre le problème des retards dans la prise de décision face à l'incertitude, nous étudions d'abord la notion d'incertitude et proposons une définition de l'incertitude adaptée au management de projet. Ensuite, le processus de prise de décision dans les projets de développement de nouveaux médicaments est modélisé, mettant en évidence le cycle de vie de l'information à partir de sa production jusqu'à sa consommation c'est-à-dire la décision elle-même. Ce modèle comprend une étape de réflexion individuelle et une étape de l'interaction en groupe, en clarifiant comment l'information est traitée différemment par les décideurs. Afin d'analyser les conflits du passé et anticiper ceux du futur, sur la base de ce modèle, un indice est défini pour mesurer le risque d'invalidation d'une décision prise *a posteriori*. Finalement, à travers des entretiens approfondis, 252 facteurs clés qui influent la prise de décision sont identifiés. Les trois causes de retard les plus citées sont : la peur de l'incertitude, la peur de la hiérarchie et la difficulté des décisions d'arrêt. Sur la base des facteurs identifiés, un recueil de bonnes pratiques est construit pour les acteurs du processus de prise de décision qui aident à former, mûrir, communiquer, digérer, respecter et finalement exécuter les décisions collaboratives.

Mots clés : indécision, incertitude, situation non urgente, modélisation de décision collaborative, bonnes pratiques, projet

Short Abstract

Collaborative decisions may be deferred when faced with a high degree of uncertainty, especially when public health and high investments are at stake and in situations that seem non-urgent, as is the case in pharmaceutical R&D projects. This thesis investigates the causes of recurrent delay in collaborative decision-making under uncertainty, and the efficient practices to reduce this delay. To better understand the problem of delay in decision-making under uncertainty, we first review the notion of uncertainty and propose a definition of uncertainty adapted to project management. Then, the decision-making process in drug development projects is modeled, highlighting the information life cycle from its generation to its consumption *i.e.* the decision itself. It includes individual reflection and group interaction, clarifying how information is processed differently by decision-makers. To analyze past conflicts and anticipate future ones, based on this model, an index is defined that measures the risk of invalidating a decision *a posteriori*. Finally, through an in-depth interview-based approach, 252 key factors that affect decision-making are pointed out. The three most-mentioned causes of delay are: fear of uncertainty, fear of hierarchy, and difficulty of No Go decisions. Based on the identified factors, a compendium of practices is constructed for the actors of the decision-making process that help collaborative decisions to be formed, matured, digested, respected, and finally executed.

Keywords: Indecision, Uncertainty, Non-emergency situation, Modeling collaborative decision-making, Best practices, Project

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List of Acronyms

AFITEP	Association Française des Techniciens et Ingénieurs d'Estimation et de Projets
AI	Artificial Intelligence
AICOSCOP	AIde à la COnception des Systèmes de COnduite des Processus
AMICE	European Computer Integrated Manufacturing Architecture (in reverse)
B	Billion
BF	Before Christ
BP	Best Practices
BPMN	Business Process Modeling Notation
CA	Chiffres d'Affaires
CIMOSA	Computer Integrated Manufacturing Open System Architecture
CIOMS	Council for International Organizations of Medical Sciences
CMMI®	Capability Maturity Model Integration
COG	Cost Of Good
CSA	Collaborative Situation Awareness
CTD	Common Technical Document
DM	Decision-Makers
DSS	Decision Support System
EC	European Commission
EMA	European Medicines Agency
EMU	European Economic and Monetary Union
ESPRIT	European Strategic Program on Research in Information Technology
FASEB	Federation of American Societies for Experimental Biology
FDA	Food and Drug Administration
FIS	Fuzzy Inference System
FonCSI	Fondation pour une Culture de Sécurité Industrielle
GMC	General Medical Council
GMO	Genetically Modified Organism
GRAI	Graph with Results and Actions Interrelated[1]
IA	Intelligence Artificielle
ICAM	Integrated Computer Aided Manufacturing
ICH	International Conference on Harmonisation
IDEF	ICAM DEFinition

[1] Graphes à Résultats et Activités Interreliés

IS	Information System
ISA	Individual Situation Awareness
ISO	International Organization for Standardization
IT	Information Technology
LEEM	LEs Entreprises du Médicament
MDA	Model Driven Architecture
MECI	Modélisation d'Entreprise pour la Conception Intégrée
NASA	National Aeronautics and Space Administration
NCE	New Chemical Entity
NME	New Molecular Entity
NTA	Notice To Applicant
OMG	Object Management Group
OPM3®	Organizational Project Management Maturity Model
PM	Project Manager
PMBOK®	Project Management Body of Knowledge
PMI	Project Management Institute
RBS	Resource Breakdown Structure
SA	Situation Awareness
SADT	Structured Analysis Design Technique
SEI	Software Engineering Institute
TPP	Target Product Profile
TTM	Time To Market
UML	Unified Modeling Language
USITC	United States International Trade Commission
WIPs	Works In Process
XML	eXtensible Markup Language
ZIFA	Zachman Institute for Framework Advancement

General introduction

Once there is a calculation, there is no decision. Decision starts where calculation stops[2].
Bruno Jarrosson

Problem of delay in collaborative decision-making under uncertainty

In all industries, decision-making in R&D projects often implies coping with uncertainty that is related to innovation. Uncertainty is related to, for example, the properties and the development process of new products, competitors' activities, changes in regulation, the behavior of consumers, the market dynamics, the shareholders' conduct, etc. Faced with such uncertainties, it might be difficult to make *important* decisions especially when public health and high investments are at stake, as is the case in the pharmaceutical industry.

Drug development projects are composed of phases of tests and studies on new compounds. At the end of each phase, a group of various experts has to decide whether the development of a new medicine should be continued or stopped. These decisions, called Go / No Go decisions, depend on the multidisciplinary results of the tests that become progressively more accurate and complete throughout the different phases of the projects. Sometimes, the results of the tests on a new compound are conclusive enough to balance its benefits against its risks. Then, a Go / No Go decision is *easily* and *rapidly* made. In other cases, the results are not conclusive enough and consequently, it is difficult to assess the benefit-risk balance of the new compounds. Additionally, Go / No Go decisions are collaborative which makes it difficult to reach a compromise. In these cases, Go / No Go decisions under high uncertainty may be either deferred, or invalidated *a posteriori*. However, to improve public health and make projects profitable, it is essential to make decisions effectively and quickly. Effective decision-making also prevents waste of time, and human and material resources and reduces Time To Market (TMM) in a competitive industrial context.

In addition to the high degree of uncertainty, some other elements may induce decision-makers to delay or invalidate these decisions: 1) human health and high

[2] « Dès qu'il y a calcul, il n'y a plus décision. La décision commence là où cesse le calcul » [Jarrosson 1994].

investments are at stake, 2) pharmaceutical R&D projects are long-lasting processes and the consequences of decisions are known only after several months or even years. Thus, decisions may seem non-emergency and delay may be tolerable, 3) sometimes, especially in the early phases of the projects, Go / No Go decisions are reversible.

The problem of delay in Go / No Go decisions in drug development projects has been identified by our industrial partner, a specialist in pharmaceutical development with 20 years of collaborative experience with several pharmaceutical companies. The symptoms which have drawn the attention of our industrial partner and his colleagues to a recurrent delay in difficult Go / No Go decision-making are as follows: 1) sometimes the same decision-makers discuss the same results several times. Thus, meetings are held and re-held without decision outcomes, 2) sometimes decisions are made but are not executed and are then invalidated *a posteriori*.

To investigate the problem of delay, we consider two distinct capabilities of decision-makers pointed out by Marquès 2011: the capacity to evaluate a situation and the capacity to decide. As Marquès 2011 states, statistical and simulation methods help decision-makers to evaluate. In pharmaceutical R&D projects, statistical and simulation methods and tools provide researchers and functional managers with relevant information about the potentially interesting compounds, especially during the research phases. At Go / No Go decision milestones, decision-makers have already been provided with the simulation results which improve their capacity to evaluate. At this level, the steering committee uses both explicit / formal and implicit / tacit / informal knowledge to shape a collaborative decision which is no longer a matter of calculation, but a "matter of compromise" [Simon 1947].

In this regard, this thesis[3] aims to identify the causes of delay and the efficient practices that reduce this delay at a level wherein informal knowledge and group interactions are involved.

Background

The situation of indecision in companies is perfectly described by Charan 2001: when a project manager finishes a proposal for a heavy investment in a new product, “the room falls quiet. People look left, right, or down, waiting for someone else to open the discussion... the meeting breaks up inconclusively” and the scene is repeated: “meetings, meetings, and more meetings...” without any decision being taken. Charan 2001 points out some causes of indecision in organizations.

Ten years after Charan’s paper, a recent study indicates that, in the literature, “there is a large body of research on when and how we make decisions, but little on when and why we do not make them” [Brooks 2011]. Similar observations [4] are made in the industrial world. For example, Davenport 2010 affirms that “very few organizations

[3] This thesis is a part of a research program lunched by FonCSI, entitled "Risk, Uncertainty and Decision-making", see http://www.icsi-eu.org/english/research/CfP-2008/CfP-FonCSI-2008-en.pdf

[4] Denis+ 2011 point out some astonishing examples of indecision: 17 years of stops and starts in the project to construct the San Francisco-Oakland Bay Bridge, 20 years in a project of personal public transportation in Paris, called Aramis that was never actually completed, 30 years in the new international airport in Lisbon, indecision culture at Yahoo, Airbus, and Boeing.

have undertaken systematic efforts to improve a variety of decisions" and Akdere 2011 points out that "organisational members are often left with making fast and rapid decisions without being furnished with the knowledge and skills to make them". "The process employed, the information used, the logic relied on, have been left up to them, in something of a black box. Information goes in, decisions come out and who knows what happens in between?" [Davenport 2009].

Thus, as we have seen in the previous paragraphs, our research is triggered by the identification of the problem of delay in decision-making by our industrial partner in pharmaceutical drug development projects. It is motivated by a lack of study about indecision, underlined in recent researches.

Approach

To understand the problem of delay in decision-making under uncertainty in drug development projects, first, the context of the pharmaceutical industry and the notions of uncertainty and indecision are reviewed. Through a brief history of the pharmaceutical industry, we describe the increasing pressures on the pharmaceutical industry and consequently, on the decision-makers in this field. We present pharmaceutical R&D projects, Go / No Go decisions, benefit-risk balances on which these decisions are based, and the difficulties relating to this balance.

After presenting the context, we seek to understand what uncertainty means. Through a look at the etymology and the history of uncertainty and the study of more recent literature, we point out the same etymological origin of decision and uncertainty and highlight two main approaches to define and process uncertainty: object-based and subject-based approaches. We show that to study the problem of delay in decision-making, when faced with uncertainty, there is a need to bring together these two approaches. Thus, we propose a more encompassing definition of uncertainty which takes into consideration the role of object, subject, and context in the generation and processing of uncertainty.

Secondly, since process modeling helps us to describe, visualize, and formalize the decision-making process, and identify the dysfunctions of the process, we model the decision-making process in pharmaceutical R&D projects. For this purpose, we use the methods and tools of enterprise engineering. This process, at a first level, highlights the activities of the different actors who contribute to the information life cycle from information collection or production to its consumption, meaning the point at which the decision is made. At a second level, to describe how the information produced is processed by different decision-makers, we propose a framework of collaborative decision-making. This framework visualizes and formalizes how information is processed differently through cognitive processes by various decision-makers. Based on this framework, an index of decision invalidation is defined which helps analyze previous conflicts in past decisions and can be used to anticipate future conflicts.

Thirdly, through an in-depth interview approach, the problematical activities of the decision-making process, some causes of delay, and some efficient practices are identified. A method is presented to analyze the content of the verbatim report of in-depth interviews and to categorize the relevant causes and practices. The results of the categorization show that causes and practices are mostly related to the culture and governance of companies, including organizational factors, and also to the mutual expectations of the actors who play different roles in the decision-making process.

Guideline for readers

As explained in the previous paragraphs, this thesis is constituted by: 1) bibliographical study, 2) process modeling through brainstorming with the industrial actors, using methods and tools of enterprise engineering, and 3) collecting and structuring efficient practices through in-depth interviews. These three items constitute the three parts of this thesis. On the first two pages of each part, the main idea of the part is presented including its Purpose, Design/methodology/approach, Findings, Originality/value, and Research implications. All these elements are also described within the parts, so some readers might want to skip these pages. Some margin notes are added which give a title to the paragraphs to which they refer, explaining the main idea of the paragraphs.

Part I

Decision-making in drug development projects

Context, particularities, and research statements

Purpose: decision-making under uncertainty is often difficult, especially when public health and high investments are at stake, as is the case in the pharmaceutical industry. The development of a new compound may be continued or stopped depending on a series of Go / No Go decisions. These decisions are based on the results of tests, which progressively become more accurate and complete over time. Faced with a high degree of uncertainty, these decisions may be delayed. The first chapter of this part aims to analyze the particularities of the pharmaceutical industry and the difficulties of Go / No Go decision-making in this context. In the second chapter, the notions of uncertainty and indecision are reviewed, so as to understand and improve decision-making processes when faced with uncertainty.

Design/methodology/approach: the methods used for this part are a literature review and a series of brainstorming sessions with our industrial partner.

Findings: an overview of the history and particularities of the pharmaceutical industry is provided. A new definition of uncertainty is proposed, taking into account four key aspects implicit in its creation and treatment: object, subject, context, and time.

Originality/value: our bibliographical study on uncertainty is not limited to recent research works. An overview of philosophical and academic definitions of uncertainty underlines the two main approaches to defining it: an object-based approach (used

in mathematics and economics), and a subject-based approach (used in human sciences). The result is a more encompassing definition of uncertainty that merges these two approaches and covers important aspects of processing uncertainty in project management: the object (a project), the subject (actors), the context (enterprise).

Research implications: this part contributes to a better understanding of the problem of delay in drug development projects, where difficult Go / No Go decisions need to be taken under conditions of uncertainty. The research questions that arise from this first part, regarding indecision in organizations, will be answered in the two following parts.

Introduction - part I

At each of the milestones of a pharmaceutical R&D project, a group of multidisciplinary experts has to decide whether the development of a new compound should be continued or stopped. These decisions, called Go / No Go decisions, are based on the results of the tests and trials which aim to determine the safety, efficacy, and quality of the new compound. The information about the properties of the compound is incomplete and uncertain, especially in the early phases of the project, and becomes more accurate and complete over time. However, even if the results are not conclusive, a decision has to be made in order to push the project forward. The problem is that a collaborative decision of this kind, when faced with uncertainty, might be deferred, while awaiting more information, especially when the time allocated to making the decision is not limited. This thesis investigates the problem of delay in collaborative Go / No Go decisions under uncertainty, in non-emergency situations.

This part includes two chapters. In the first chapter, the context of the pharmaceutical industry and its specificities involving risky, expensive, and lengthy projects are described, so as to better understand Go / No Go decisions.

In the second chapter, to investigate indecision in the face of uncertainty, two notions of uncertainty and indecision are reviewed. First, the history of uncertainty and its academic definitions are summarized and two main approaches to define uncertainty are outlined: the object-based approach (used in mathematics and economics), and the subject-based approach (used in psychology). However, in project management, both object (a project) and subjects (actors) should be taken into account to process uncertainty and reach the project's goals. Thus, we propose a definition of uncertainty in which the two main existing approaches converge. Secondly, the notion of in/decision is reviewed, studying its potential causes and its possible forms. This review reveals that although the problem of indecision has been studied in depth in its individual dimension, its collaborative dimension has been somewhat neglected. At the end of this part, our research questions are stated. These will be answered in the two following parts.

1

Difficult decisions in pharmaceutical R&D projects

Poisons and medicines are oftentimes the same substance given with different intents.
Peter Latham

“Things are better controlled if they are better understood” [Vernadat 1996]. Knowledge acquisition in a given industrial field and its specificities helps to understand the context in which projects are conducted. Internal reports, bibliographical and field studies, including observation, interviewing, and questionnaires, are some potential sources of knowledge that help describe and model a decision-making process and then allow it to be improved. This chapter is based on a bibliographical study and discussions with our industrial partner.

1.1 Specificities of the pharmaceutical industry

“Pharmacy is concerned with all aspects of the preparation and use of medicines, from the discovery of their active ingredients to how they are used” [Anderson 2005]. The purpose of the pharmaceutical industry is to research, develop, manufacture, and sell medicines for preventive or curative treatments [Gourc 2000]. The main specificity of this industry is that public health is directly at stake, which today implies close regulation and supervision by regulatory authorities, guaranteeing the safety, efficacy, and quality of new medicines. Pharmacy research tools and methods have evolved through the centuries and the regulations change every day. To understand the context of the pharmaceutical industry today, it is useful to look at the history of pharmacy, which is "as old as humanity itself" [Simon 2005].

1.1.1 A brief history of the pharmaceutical industry

The use of plants and animals as medicines goes back to the Antiquity [Zanders 2011]. The history of pharmacy is "a large and complex story" which has its specificities in different countries [Anderson 2005]. However, three revolutions marked the course of this history.

Before the late 19th century, pharmacists were making their drugs themselves from various vegetable or mineral substances, using *recipes* collected in pharmacopoeias [Dubois+ 1580; GMC 1864].

Revolution of chemistry and biochemistry

Modern pharmaceutical research began in the 19th century with the development of organic chemistry [Zanders 2011]. The late 19th - mid 20th century was marked by the discovery of major active substances such as aspirin[1] (1829), insulin[2] (1922), penicillin[3] (1928), and the first vaccines. Therapeutic research was booming and gave birth to the pharmaceutical industry, with the development of synthetic drugs in chemistry.

"Many drugs have been discovered by accident" [Zanders 2011]. Ban 2006 underlines four types of serendipity[4] in pharmacy, meaning finding a medicine:

– while looking for something else such as aniline purple, penicillin, lysergic acid diethylamide, meprobamate, chlorpromazine, and imipramine. The most famous new drug, penicillin, was discovered when one of Fleming's staphylococcus culture plates had become contaminated and developed a mold that created a bacteria-free circle, while he worked on influenza,

– through "an utterly false rationale" such as potassium bromide, chloral hydrate, and lithium. Potassium bromide, the oldest widely-used sedative[5], is used by internist Lockock to control epilepsy by reducing masturbation. Lockock, like most physicians of his time, believed that there was a relationship between masturbation and epilepsy and Bromides were known to decrease the sex drive [Lehmann+ 1970],

– a valuable indication is found which was not initially sought such as iproniazid which is used in the treatment of tubercular patients and its side effects led to the development of monoamine oxidase inhibitors for the treatment of depression,

– by "sheer luck" such as chlordiazepoxide in 1957 which is followed by diazepam (Valium®) in 1963. The flask of chlordiazepoxide "was found, literally during a laboratory clean-up".

It should be noted that serendipitous drug discoveries are also the result of the curiosity and passion of the receptive minds of the pharmacists and chemists. Unforeseen events have their place in research, as in any human activity [Dousset 2003], but as Pasteur states[6] (1822-1895): "chance only favors the prepared mind"[7] [Vallery Radot 1924]. During this "golden age" of drug discovery many drugs

[1]The Nobel Prize in physiology or medicine 1982 was awarded jointly to Sune K. Bergström, Bengt I. Samuelsson, and John R. Vane. For more information see [Jack 1997].

[2]The Nobel Prize in physiology or medicine 1923 was awarded jointly to Frederick Banting and James J. R. Macleod. For more information see [Bliss 1993].

[3]The Nobel Prize in physiology or medicine 1945 was awarded to Alexander Fleming. "The improbable chain of events that led Alexander Fleming to discover penicillin in 1928 is the stuff of which scientific myths are made" (100 People of the Century, TIME Magazine, `http://www.time.com/time/`).

[4]The origin of this word is in a Persian fairy tale: The Three Princes of Serendipity (old Persian name of Sri Lanka). The heroes of this tale were "always making discoveries, by accidents and sagacity, of things they were not in quest of" [Remer+ 1965].

[5]Bromide salts were "undoubtedly effective", although today they are eliminated from clinical use because of their relatively low efficacy coupled with high toxicity [Ewing+ 1965], compared to new products.

[6]Pasteur correctly developed the theory of immunization from an accident. Pasteur went on holiday. His assistant, Charles Chamberland, did not inoculate a clutch of hens with cultures of chicken cholera as he had been told to. Upon his return, Pasteur decided to test 1-month-cultures on the hens. The results were unexpected. At first, the hens became ill and then recovered [Dixon 1980]

[7]« Dans les champs de l'observation, le hasard ne favorise que les esprits préparés. » Pasteur

were developed that we use today [Zanders 2011]. Today, the comparison of pharmacovigilance data bases helps drug repositioning[8] based on unexpected events. In recent years, the term "systemizing serendipity" [Datamonitor 2008] is used to name rational approaches to drug repositioning that aims to discover / explain new pharmacological mechanisms of action for known molecules. Sildenafil is an important example of drug repositioning [Barratt+ 2012] which is an inhibitor that dilates cardiac vessels with an unexpected side effect of penile erection and is sold as Viagra® [Ban 2006].

Revolution of computers

The revolution in chemistry was followed by that of computers and robots which changed, in turn, the mode of drug discovery and manufacturing. Sykes 1997 describes this revolution: "the old paradigm for drug discovery was one chemist, one week, one molecule. Now, that one chemist, with one computer and one robot is capable within one week of producing at least 10,000 molecules."

Revolution of biotechnology

The third revolution is that of biotechnology, which is the "use of living organisms and their components in agriculture, food, and other industrial processes" [Bhatia 2005]. The pharmaceutical industry is probably the most affected, of all industries, by biotechnology. Biotechnology products include vitamins, hormones, more potent antibiotics, and specific clinical substances used in pregnancy and diabetes tests [USITC 1984]. Biotechnology is considered as the future of pharmacy. The success of the biomedicines market is mainly due to monoclonal antibodies, in the field of oncology[9]. In 2009, there were more than 20 monoclonal antibody-based drugs on the market, including several blockbusters [Patlak 2009]. In 2010, 50% of the drugs developed were in biomedicines[10] [Bohineust 2010], where monoclonal antibody-based drugs represent 40.1% of the biomedicines market[11].

Changes in regulation

In parallel with these revolutions, the regulation of medicines also evolved: until the mid-20th century, clinical observation of some patients was sufficient to demonstrate the therapeutic benefits of a molecule. Today, thousands of observations are required to obtain marketing authorization. The "modern" regulatory system came into force after the Thalidomide®[12] tragedy, also known as Contergan [Mussen+ 2010]. The Thalidomide® catastrophe occurred because, at that time, the study of reproductive toxicity in different animal species had not been elaborated. Reproductive toxicity studies became very important after this tragedy [Gad 2008]. This catastrophe demonstrated the failure of traditional regulations in the era of industrial research, and "made it clear just how complex the medical market had become" [Quirke+ 2008]. Consequently, the regulations have changed and become increasingly strict: "in spite of the ever-increasing spending on R&D over the last decades, the number of

[8] "Drug repositioning is a promising field in drug discovery that identifies new therapeutic opportunities for existing drugs." [Macor 2011]. "Drug repositioning / indications discovery has historically been the result of serendipity" [Barratt+ 2012].

[9] Source: `http://www.glycode.fr/pages/les-enjeux-economiques.html`

[10] « La biotech, science des organismes vivants, est considérée comme l'avenir de la pharmacie : 50 % des médicaments sont aujourd'hui développés dans cet univers » [Bohineust 2010].

[11] Source: `http://www.glycode.fr/pages/les-enjeux-economiques.html`

[12] Thalidomide® "was undoubtedly the most significant adverse event in pharmaceutical industry" [Mussen+ 2010]. It was introduced in 1957 as a sedative or hypnotic for morning sickness of pregnancy. The extremely rare deformities of the newborn babies were reported such as the absence of hands and/or feet [Burley 1988]. The latest news about Thalidomide® is that "makers of Thalidomide® apologized after 50 years", see `http://transcripts.cnn.com/TRANSCRIPTS/1209/01/cnr.07.html`

New Molecular Entity (NME) approvals has declined significantly" [Sanchez Serrano 2011]. In Europe, marketing authorizations dropped by half between 1992 and 2008 [Bohineust 2010].

Another change was that the Thalidomide® scandal was followed by Radio, TV, and newspaper reporters. "The role of the public became visible... [and] drugs had become an everyday consumer good" [Gaudillière+ 2008]. The role of media has been studied in other affairs[13].

Increasing pressure on healthcare finance is another reason for change in the external business environment of the pharmaceutical industry. The healthcare budget is a considerable part of public expenditure, "even in the USA where private medicine is dominant" [Sykes 1997]. In the early 1990s, sluggish economic growth, elevated unemployment rates, and ageing demographic profiles increased pressure on welfare policies. European Economic and Monetary Union (EMU) imposed restraints on social spending. French and German authorities adopted reforms in social-insurance policies such as healthcare [Vail 2009]. In 2008, the financial crisis drove governments to take measures in order to restrict reimbursements, decrease medicine prices, increase generic and substitute medicines, and demand strong proof of value [Behner+ 2009]. This crisis forced laboratories to find sources of savings rapidly through, for example, acquisitions. Four of the biggest American laboratories thus restructured: Pfizer acquired Wyeth Group, Merck & Co. acquired Schering-Plough Laboratory, Abbott acquired the pharmaceutical subsidiary of the Solvay group... [LEEM 2012].

In sum, the main changes through this brief history of pharmacy can be summarized as follows:

- **scientific and technological changes** have multiplied the number of choices of new molecules in a reduced time and offered opportunities to discover new medicines, but have not necessarily facilitated drug candidate selection. Similarly, biotechnology is now essential in the discovery of new molecules, but it operates in a different culture from the culture of origin of the chemical laboratories. Therefore, uncertainty has increased in the new era of the pharmaceutical industry. In this "very complex industry", companies need to adapt to changes in order to make science and technology work with business in a way to satisfy all stakeholders [Baines 2010],
- **considerable changes in regulation** which imply high safety, efficacy, quality, and also innovation of a candidate drug, compared to existing medicines in the market: health authorities have become "more demanding" [Bohineust 2010],
- **rise in public awareness** which changes the "traditional" relationship between industry, doctor, and patient. Internet now gives information to patients who are becoming "more demanding of their healthcare providers" and sometimes obliges companies to justify their development decisions [Sykes 1997]. Thus, patients have became the actors in their own health,

[13] Pieters+ 2008 study the role of TV in Halcion® (triazolam) affair. Gabe 1997 considers that scientific information circulates in professional and non-professional circles and Lasagna 1980 states: "whatever the final verdict on triazolam may be, there is reason to question whether regulatory decisions forced by flamboyant media coverage are in the public interest."

Table 1.1: High expenditure rate in pharmaceutical R&D, presented in billions of dollars and as a percentage of turnover [Bohineust 2010]

Laboratories	Merck & Co.	Roche	Novartis	Pfizer	Sanofi-Aventis	GSK
R&D budget	$5.8 B	$9.3 B	$7.5 B	$7.8 B	$6.2 B	$6.3 B
Turnover	21.2%	20.1%	17%	15.7%	15.6%	14.4%

- **pressures on healthcare finances** which represents an important proportion of government expenditure in all developed economies. “Pressure on public finances converts into pressure on healthcare costs” [Sykes 1997].

The history of the pharmaceutical industry shows that it is subject to various kinds of changes, uncertainties, and pressures. These changes imply rapid adaptation to the environment which demands safer, more innovative, and less expensive drugs, while the pharmaceutical R&D expenditure is high and continues to increase. In this context, the choice of molecules to be developed is primordial to ensure public health and promote the economic growth of the pharmaceutical industry. Thus, the *right* choices must be *rapidly* made at the outset of the project to take the opportunities of developing safe and effective medicines and to limit the consumption of resources by those that do not prove to be safe and effective. This pressure influences the behavior of decision-makers who are perfectly aware of the impacts of their decisions, especially in the particular economic context of pharmaceutical R&D projects. In order to better understand this context, in the next section some economic specificities of the pharmaceutical industry are outlined.

1.1.2 Economics of the pharmaceutical industry

Some specificities distinguish the economics of the pharmaceutical industry from other industries:

- high expenditure rate in R&D. For example, in France, the total budget for research is certainly lower in absolute value than for the car industry, but it represents 12.3% of the turnover of pharmaceutical companies, compared to only 4.2% for the car industry [LEEM 2008] and continues to increase. For the six companies mentioned in tab. 1.1, the R&D budget reaches $42.9 billion in total. It represents an average of 17.33% of their turnovers [Bohineust 2010],
- the pharmaceutical industry is highly fragmented, since no pharmaceutical company held more than 10% of the market share in 2000 [Gourc+ 2000] and despite the mergers and acquisitions that regularly make the headlines of the financial press, the world leader, Pfizer, held only 6.6% of market share in 2011, and the first five groups[14] represent 26% of the global market against 40% in the computer industry, 50% in the car industry, and 80% in the aerospace industry [LEEM 2012],

[14] Pfizer (USA): 6.6%, Novartis (Switzerland): 6.0%, Merck & Co. (USA): 4.7%, Sanofi-Aventis (France): 4.6%, AstraZeneca (United Kingdom): 4.3%, source: Intercontinental Marketing Services-Health (IMS-Health).

– the duration of pharmaceutical R&D projects is, on average, more than 13 years [Paul+ 2010], while the length of drug patent protection is 20 years, starting from the date of invention. Thus, as one project manager emphasizes, "less than seven years remain before the entry of the first generic medicines onto the market". Until the mid-1980s, the revenues from branded drugs decreased gradually after the expiration of their patents. Today, revenues from multibillion-dollar blockbusters plunge by 90% in a few weeks after the expiration of their patent protection [Garnier 2008].

In this rapidly-changing and highly-competitive context, it is crucial that pharmaceutical actors make Go / No Go decisions effectively and rapidly in order to make projects profitable. As Midler 2004 emphasizes, in pharmaceutical R&D projects, speed is a decisive criterion, not only because of the economic bonus of being first-to-market, but also because the authorities are now tending to refuse marketing authorization for medicines whose effects are similar to existing ones[15]. However, as some actors complain, some of Go / No Go decisions are frequently delayed. In the next section, we explain different phases of the pharmaceutical R&D projects, Go / No Go decisions, their specificities, and their difficulties.

1.2 Specificities of the pharmaceutical R&D projects

1.2.1 Phases of drug discovery and development projects

A drug development project is defined as a process of knowledge acquisition on a presumably active chemical or biological entity that may become a new medicine [Gourc+ 2000]. Developing a new medicine is very different from the creation of a manufactured product. This is a long, risky, and technologically and commercially complex process[16] [Midler 2004].

A lot of questions have to be answered in order to know the behavior of a new compound in the human body, including its absorption, distribution, metabolism, mechanism of action, side effects, elimination, etc. Drug discovery and development projects are composed of several phases of trials that aim to answer these questions progressively, in accordance with the Notice To Applicant (NTA)[17] [EC 2008].

Fig. 1.1 illustrates the phases of pharmaceutical R&D projects, composed of discovery and development phases. Discovery phases[18] are composed of Target-to-hit, Hit-to-lead, and Lead optimization phases, which aim to identify disease mechanisms

[15] "Le critère de vitesse est ici tout à fait déterminant. Arriver au premier dans la course aux nouveaux médicaments actifs pour une pathologie donnée est décisif, non seulement à cause de la prime économique que donne naturellement cette position, mais aussi parce que, pour limiter l'augmentation des dépenses de santé liées à la multiplication de nouveaux médicaments, les autorités régulatrices tendent aujourd'hui de plus en plus à refuser l'autorisation de mise sur le marché de produits dont les effets sont proches d'autres qui existent déjà" [Midler 2004].

[16] "Un développent en pharmacie est bien différent de la création d'un produit manufacturé, mais il n'a rien à envier sur le plan de complexité, à un projet automobile par exemple. C'est une opération longue, hasardeuse, complexe technologiquement et commercialement" [Midler 2004].

[17] The NTA produces a series of regulatory guidances to assist pharmaceutical actors in the preparation of the results of studies on medical products, in an acceptable format. "NTA has been prepared by the European Commission in consultation with the competent authorities of the Member States, the European Medicines Agency and interested parties in order to fulfil the Commission's obligations" [EC 2008].

[18] These research phases correspond to research into new chemical compounds and are a little different for biomedicines.

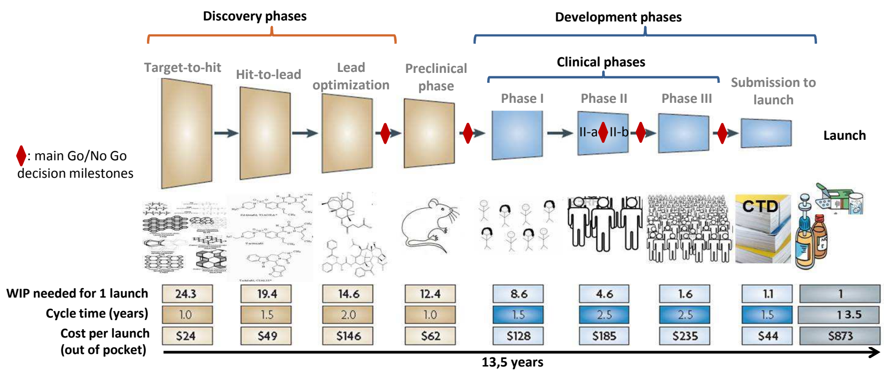


Figure 1.1: Different phases of drug discovery and development projects, adapted from Paul+ 2010

and the functions of potential target drugs, to confirm the chemical structures of new compounds, and to improve their properties. The development phases[19] include preclinical, clinical, and submission phases. In these knowledge acquisition processes, different information about the new molecules is produced gradually when the results of each phase become available. At the end of each phase, based on the available results of the trials, a Go / No Go decision must be made on transition to the next phase.

In the preclinical phase, the compound is tested on animals, in order to determine the maximum non-toxic dose and examine the efficacy of the drug. In phase I, the compound is tested on some healthy subjects, to find tolerable dose ranges. The main goal of the trials in phase II is to establish the efficacy and safety windows of the compound in the target population (patients), by identifying the minimum effective and the maximum tolerated doses on this population. In phase III, the compound is tested on a large number of the target population, in order to identify side effects. In parallel, the route of administration, the availability and mode of production of the new compound are also studied. The results for the safety, efficacy, and quality of the compound in animal and human subjects become progressively available through the project phases. If, at the end of the phase III, a Go decision is made for submission to launch, the results of the tests and studies must be presented in an internationally accepted format, called a Common Technical Document (CTD)[20], to be submitted to regulatory authorities.

As fig. 1.1 shows, a pharmaceutical R&D project lasts on average over 13 years and costs about $873 million, including the cost of the stopped processes to achieve one NME launch [Paul+ 2010]. Garnier 2008 estimates a cost of more than $1 billion – a figure higher than NASA's budget for sending a rocket to the moon. The success rate of pharmaceutical R&D projects is only 4%, meaning more than 24 Works In Process (WIPs) are needed to achieve one NME launch [Paul+ 2010].

As we have seen in this section, pharmaceutical R&D projects involve considerable time and financial investment. The accomplishment of these projects depends on

[19] These development phases are common to chemical medicines and biomedicines.

[20] "The CTD is an internationally agreed format for the preparation of applications to be submitted to regulatory authorities in the three International Conference on Harmonisation (ICH) regions of Europe, USA and Japan. It is intended to save time and resources and to facilitate regulatory review and communication… The CTD gives no information about the content of a dossier and does not indicate which studies and data are required for a successful approval" [EC 2008].

Go / No Go decisions wherein the degree of uncertainty is high and human health and high investments are at stake. In the next section, we shall see on what basis these high-stake decisions are taken.

1.2.2 Difficulty of Go / No Go decisions based on the benefit-risk balance

Go / No Go decisions are made by a steering committee which includes various experts: chemists, pharmacologists, toxicologists, clinicians, marketeers, etc. According to the phase of the project, different weights may be given to different experts' opinions.

To decide whether to continue the project, experts assess a benefit-risk balance of the new compound. In the European pharmaceutical legislation, benefit-risk balance is defined as "an evaluation of the positive therapeutic effects of the medicinal product in relation to the risks"[21]. The benefits of the new medicine, which are "the helpful effects you get when you use the medicine", and the risks, which are "the chances that something unwanted or unexpected could happen to you when you use the medicine", are evaluated and balanced out [FDA 2002].

At the end of a phase, the results of the trials and studies may be conclusive enough, meaning *good* enough to continue the development or *bad* enough to stop it. In these cases, the benefit-risk assessment is clearly conclusive and the Go / No Go decision is *rapid*. Today, when a molecule is toxic in one species, its development is stopped in line with the principle of precaution and the respect of ethical values. Toxicology suffer no procrastination and a No Go decision is thus *easy* and *rapid*. Such standards mean that some drugs approved in the past and currently on the market would not be approved today because of their contradictory results on different animal species: "aspirin would not be approved today" [Pizzorno+ 2010], since poorly tolerated by rabbits [Kohn+ 1997]. "Aspirin and Tylenol® kill cats, penicillin kills guinea pigs, Advil® and Motrin® cause severe gastric problems in dogs, Dristan® is harmful to cats, [and] eye drops can cause blindness in animals" (Dr. Roy Kupsinel in [Silverman 2004]).

In other cases, the results are not conclusive enough to assess the benefit-risk balance and Go / No Go decisions are difficult to make. For example, efficacy tests on different kinds of animals during the preclinical phase may give contradictory results and then not be conclusive enough to begin tests on human subjects at the clinical phase. In these cases, a Go decision implies taking risks on human health and the additional investments that might be lost if the results of the next phases are *bad* and development is ultimately stopped at a later date. A No Go decision stops the development of a medicine that may be safe and effective on human subjects. It also implies accepting the loss of the investment in the performed phases, while decision-makers are unsure about the properties of either the studied compound, or the potential competitive drugs.

To understand the problem of delay, the difficulties[22] of the benefit-risk balance are reviewed in the next section.

[21] Directive 2001/83/EC of the European Parliament and of the Council of 6 November 2001, available in http://ec.europa.eu/health/files/eudralex/vol-1/dir_2001_83_cons/dir2001_83_cons_20081230_en.pdf

[22] Most of these difficulties are discussed, from the point of view of the health authorities, in more detail by Mussen+ 2010.

1.2.2.1 Great deal of information required to assess the benefit-risk balance

Benefit-risk assessment involves reviewing a large amount of relevant information generated over several years of tests and studies to know the properties of a new compound. Different dosages and forms of the compound are tested on various animal species, and different sub-populations of the target population such as old people, children, pregnant and nursing women. Additionally, drug-drug interactions should also be considered for the possible cases of co-administration of multiple drugs [Wang 2007].

Often a development candidate is tested for several therapeutic indications or in different formulations [Kennedy 1998] and a benefit-risk assessment is necessary for each therapeutic indication [Mussen+ 2010]. The seriousness of the disease also needs to be taken into consideration: "acceptable risks for anti-cancer medicines are not acceptable for most other indications", according to one expert.

The difficulty of benefit-risk balance is not only related to the quantity of multidisciplinary information to be taken into account. The uncertainty of this information also causes difficulty in assessing the benefit-risk balance.

1.2.2.2 Uncertainty of the benefit-risk balance

Benefits and risks cannot be completely known, particularly in the early phases of a project, because:

1. the paradigm of these projects is that the information about the safety, efficacy, and quality of the molecules is produced progressively throughout the different phases. At the end of each phase, decision-makers would like to know more to make a Go / No Go decision. The question is whether it is relevant / appropriate to seek to know more before deciding, or whether the available elements are sufficient,
2. the results of studies may include some incomplete or even contradictory information, which becomes available and more accurate progressively,
3. the results of studies and trials on thousands of patients, even when coherent and complete, cannot incontestably predict the benefits and the risks of a new compound for the millions of patients of the final target population.

At the end of the project, regulatory authorities assess a *final* benefit-risk balance to approve a new medicine. At that time, all trials and studies are finished on a relatively small number of patients, 4,000-10,000, compared to the several millions that may use the medicine after its commercialization. Therefore, even at the time the product is ready to be launched on the market, it is difficult to assess the benefit-risk balance over a long-term period and on a large target population. "This difficulty can also be shown by some divergences of opinion of the Food and Drug Administration (FDA) and the European Medicines Agency (EMA) about the same molecules. It shows how benefit-risk assessment can be less obvious during development phases, when all results are not yet known" an expert indicates.

As fig. 1.1 shows, for each successful process, about 23 development processes are stopped in different phases. For example, in a full 50% of projects that are ultimately abandoned, failure is due to lack of therapeutic efficacy compared to placebos, and 31% to lack of safety [Gordian+ 2006].

1.2.2.3 Different natures of the benefits and risks

Benefits and risks are not of the same nature and dimensions [Herxheimer 2001]. Benefit is a quantity and risk is a probability. A minimal benefit with a probability of 99% is usually not tempting and a tiny risk with a probability of 1% cannot always be ignored [Cheung+ 2001]. Additionally, the long-term benefits have to be balanced against the short-term risks, or *vice versa*. For example, with a contraceptive, the benefit of not getting pregnant tomorrow must be balanced with the risk of venous thrombosis in 15 to 25 years [Herxheimer 2001]. Thus, in most cases neither the benefits nor the risks can be compared quantitatively in a simple and appropriate way [CIOMS 1998].

1.2.2.4 Evolution of the benefit-risk balance

A benefit-risk balance evolves as new data comes to light through the various phases of the project. This assessment is dynamic over time, for two reasons: first, a revealing of information about the medicine itself: a medicine can be considered safe for several years, but ultimately deemed unsafe after the discovery of new risks. Such was the case for rofecoxib, for example. Secondly, new information may emerge about a competing medicine that affects the benefit-risk balance of the studied medicine, such as a new anti-cancer drug when compared to previous ones [Mussen+ 2010]. About 19% of ultimately- abandoned projects concerned medicines that were not safer or more effective than the medicines already available on the market [Gordian+ 2006].

Furthermore, the benefit-risk balance of a compound may be considered differently, depending on the new information about the other projects in the firm's pipeline.

1.2.2.5 Subjectivity of the benefit-risk balance

In addition to the objective difficulties, benefit and risk, as fundamentally evaluative terms, involve subjective value judgments. This judgment must be based on facts about the effects of the medicine. But it is also superimposed by cultural, social, philosophical, political, and religious values [Veatch 1993]. "Benefit-risk assessment is essentially a value judgment, inevitably it will be prone to a number of biases" [Bowen 1993]. Thus, benefits and risks are compared and perceived differently by various actors, using different criteria [Bowen 1993]. Mussen+ 2010 and Spilker 1994 present these actors: 1) pharmaceutical companies, who produce medicines, "view benefits in terms of their ability to demonstrate sufficient efficacy", 2) regulatory authorities who approve medicines, "view benefits and risks for the nation as a whole rather than for individuals", 3) third-party payers who reimburse, 4) physicians who prescribe, and 5) patients who use medicines and as Veatch 1993 indicates often have a very personal point of view. Thus, the pharmaceutical actors, who are the first to assess the benefit-risk balance of a new compound, should consider the possible reflections of the regulatory authorities, health insurance institutions, physicians, and patients. It makes assessing this balance more difficult, compared to an objective evaluation that has more chance of being accepted by everyone. Even within a company, focuses on risks and benefits are not the same for different actors. Traditionally, R&D staff focus primarily on risks, whereas, marketers and advertising staff focus on benefits [Mussen+ 2010]. Thus, in addition to the objective difficulties of benefit-risk balance, subjective value judgments make reaching a compromise on this assessment more difficult, given that a benefit-risk assessment in a firm has to be accepted by society in the future.

Two other elements, which are not considered as difficulties, might induce decision-makers to postpone or invalidate Go / No Go decisions. First, Go / No Go decisions are often reversible. New information about the compound may call into question a previous decision. Such a decision does not have a "stable" but rather a "fragile" status. Secondly, Go / No Go decisions may not seem urgent, compared to emergency situations such as accidents, crises, or disaster contexts wherein an immediate decision and reaction is necessary and its consequences can often be known immediately. Pharmaceutical R&D projects last more than ten years and the consequences of Go / No Go decisions are not immediate, thus delays of several months may be ignored or tolerated.

1.3 Formulation of the problem of delay in drug development projects

In this chapter, we have seen that pharmaceutical R&D projects are risky, expensive, and long-lasting projects that have to be accomplished in a changing and uncertain context, with strict regulation and ever tighter healthcare budgets. Several Go / No Go decisions have to be made throughout these projects to continue or stop the development of the new compounds, depending on their benefit-risk balances.

In this context, Go / No Go decisions are characterized by: 1) a high degree of complexity: a large amount of inter-connected information from various fields must be taken into account to make Go / No Go decisions, 2) a strong degree of uncertainty: Go / No Go decisions are taken under uncertainty due to the lack of knowledge about the safety, efficacy, and quality of the new compounds, and also about competitors' activities, 3) reversibility of decisions: Go / No Go decisions are not definitive and can be revised, 4) non-emergency situations: the long duration of these projects may induce experts to think that they have enough time to decide, 5) the collaborative aspect: Go / No Go decisions are made by a steering committee wherein individual differences and interactions between experts may complicate the decision (or indecision) process.

All these elements, related to the context of Go / No Go decisions, may end up as brakes on decision-making. However, if a compound is going to become a successful drug, it should be commercialized quickly to minimize Time To Market (TTM) and optimize the profits before the entry of the generic (see section 1.1.2 on page 13), in order to cover the cost of the failed projects. If a compound is going to fail, it should fail as soon as possible to prevent wasting more investments. Therefore, delays in decision-making in the development process may cause heavy losses in the commercialization period. Hence, it is necessary to understand and analyze the problem of delay in order to reduce it.

In order to better understand the problem of delay in difficult Go / No Go decisions and to define and position our research questions, the notions of in/decision and uncertainty are reviewed in the next chapter.

2

Indecision problem in the face of uncertainty

The only thing that makes life possible is permanent, intolerable uncertainty; not knowing what comes next.
Ursula K. Le Guin

The survival and evolution of *Homo sapiens*, through natural selection, is due to his decision-making capacities which result in flexible behavior [Mithen 1990] under uncertainty. Conscious decision-making is maybe our most fundamental capability. "In order to understand this capability, we need to understand the notion of uncertainty first" [Klir 2005], especially when decisions are delayed in the face of uncertainty. Thus, in the first section of this chapter, we aim to understand what uncertainty means. Through a look at the etymology and the history of uncertainty and the study of more recent literature, we highlight two main approaches to define and process uncertainty: object-based and subject-based approaches. We show that to study the problem of delay in decision-making, when faced with uncertainty, there is a need to converge these two approaches. Thus, we propose a more encompassing definition of uncertainty, taking into account the role of object, subject, and context in the generation and processing of uncertainty.

After defining uncertainty, coming back to the problem of indecision, an overview of the causes of indecision is presented. We show that the causes of indecision are tightly interconnected with the factors that generate uncertainty or help process it. Specifically, the causes of indecision related to: 1) the object *i.e.* to imperfection of information about an object, which is studied in AI, 2) the subject *i.e.* to the personality of the decision-maker, which is widely studied in psychology, 3) the context *i.e.* to the situation and organization wherein decisions are made. The causes related to the context, as some recent works indicate, are less frequent in the literature [Davenport 2010; Denis+ 2011]. We present a summary of the few existing studies on indecision in organizations. Finally, we formulate our research questions, so as to investigate the problem of delay in collaborative decisions in organizations.

2.1 Characterizing uncertainty

Uncertainty is commonly found in daily life and in several scientific fields. In daily life, uncertainty is associated either to the unpredictability of an unexpected event and its consequences, or to the consequences of an intended, programmed event or action. In the first case, things do not turn out as expected; for example: the attacks on the Twin Towers on September 11th 2001, the financial crisis in 2008, the A H1N1 pandemic[1] in 2009, the Deepwater Horizon oil spill caused by British Petroleum in 2010, the Icelandic volcano eruptions: Eyjafjöll in 2010 and Grímsvötn in 2011 that cause the cancellation of thousands of flights. Thus, an unexpected event immediately disturbs the course of actions and its evolution and consequences are unknown. In the second case, the consequences of something programmed remain indeterminate for a long time, for example the result of a presidential election, the consequences of a court verdict, the exhaustive consequences of Genetically Modified Organism (GMO), the impacts of Greece's renewed budget plan, etc.

In scientific fields, uncertainty is a factor either in understanding the world or in controlling it and adapting decisions and actions. In the first case, scientists aim to understand the world and an immediate control is not intended. For example, NASA sends the Curiosity Rover[2] to Mars or palaeontologists will study the frozen mammoth found in Siberia, which died around 30,000 years ago [3]. In the second case, uncertain information is processed to forecast weather or the trends on the stock markets, to make smarter robots, etc.

What are the common points in all these uncertainties in various fields? To understand why sometimes decisions are deferred in the face of uncertainty, we aim to define and characterize uncertainty. In this section of this chapter, we answer the following questions[4]. What is the etymological root of uncertainty? What is the link between uncertainty, decision, and risk? How is uncertainty perceived and treated in different periods by human beings? How is uncertainty defined in dictionaries and in the scientific literature?

2.1.1 Etymology of uncertainty and its link with decision

Same root of uncertainty and decision

The word uncertainty comes[5] from vulgar Latin *certanus*, which is from Latin *certus*, originally a variant past participle of *cernere*, meaning "to distinguish, decide", literally "to sift, separate". *Cernere* comes from Proto-Indo-European root *krei* which is also the root of "crisis". The verb "decide" comes from the Latin *decidere*, "to decide, determine", literally meaning "to cut off".

This origin indicates: 1) **uncertainty and decision have the same root** and are tightly interconnected, 2) making a decision implies *not possessing a whole after cutting* and thus a sense of loss, 3) crisis branches from the same root. In the next section, to better understand the notion of uncertainty today, we present an overview of the philosophical visions of uncertainty through the centuries. It shows how the conception of uncertainty evolved in human awareness.

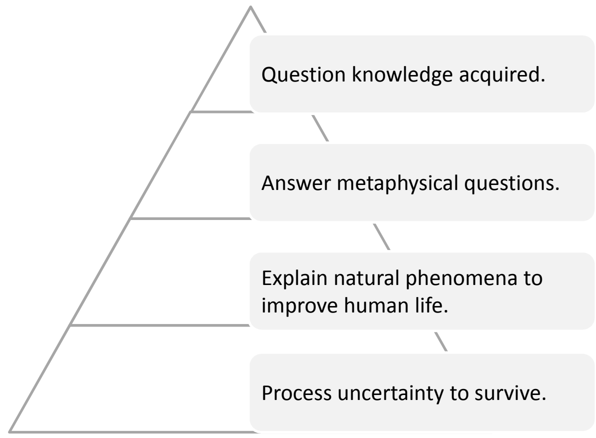


Figure 2.1: Motivations of human beings for dealing with uncertainty

2.1.2 A brief history of uncertainty

A common point of the different reactions of human beings to uncertainty is an effort to eliminate it. The motivations and means used by humanity to eliminate uncertainty were diverse in different ages. In this regard, we can identify four major motivations: to survive, to live, to answer questions on human existence, and to question the knowledge obtained. Fig. 2.1 shows the four levels that we distinguish:

Four levels of uncertainty treatment throughout history

1. in prehistoric times, the treatment of uncertainty was a vital issue for our ancestors *Homo sapiens*. They lived in a predator environment. The survival instinct was thus the first decision tool faced with uncertainty. Evolution chose a brain anatomy which *best* dealt with uncertainty[6].
2. in the age of the Antiquity, human beings began to ask less vital questions, seeking out explanations to understand natural phenomena. The question of survival was transformed into a question of living conditions.
3. then, human beings dealt with uncertainties regarding their own existence. In those ancient times, the myth was probably the first attempt to reduce uncertainty [Bronner 1997]. Witchcraft, by predicting the future, was a means to guide decisions. Religion in turn, by providing answers to metaphysical questions, provided an account to create certainty. Logic and mathematics proposed reasoning rules to reduce uncertainty and provide methods and tools to create certainty, such as surveying and accounting [De Wilde 2010].
4. having survived and begun to better understand their physical environment, and found or invented some answers to metaphysical questions, humans

[1] Steyer+ 2010 study the treatment of uncertainty in the time of the A H1N1 flu pandemic in companies.

[2] http://www.nasa.gov/mission_pages/msl/msl5things20100916.html

[3] 5th October 2012: "the remains of a woolly mammoth have been found by an 11-year-old boy in a remote part of northern Russia", http://www.bbc.co.uk/newsround/19848152

[4] A more complete version of this section is presented, in French, in the FonCSI industrial notebook [Hassanzadeh+ 2011a], available in: http://www.foncsi.org/media/PDF/CSI-incertitude-approches.pdf

[5] http://www.etymonline.com/index.php?term=certain&allowed_in_frame=0

[6] History of decision-making under uncertainty, presentation of Philippe De Wilde, 2010, Department of Computer Science Heriot-Watt University Edinburgh [De Wilde 2010], available in: http://www.macs.hw.ac.uk/~pdw/main1.pdf

Highest

	Metaphysics	Epistemology	
Being	Higher Forms – The Good	A. Understanding	Knowledge
Being	Lower Forms – Human Forms	B. Reasoning	Knowledge
Becoming	Sensible Objects	C. Perception	Opinion
Becoming	Images and Shadows	D. Illusion	Opinion

Lowest

Figure 2.2: Platonic view of knowledge path, from [Allert 2002]

began to question their own knowledge. The philosophers were the first to formulate questions on the objectivity and subjectivity of certainties.

The ancient philosophers underlined the importance of distinction between subjectivity and objectivity through the illusion in subjectivity and the contribution of reason in objectivity:

- Socrates (5th century BC) said that believing in some uncertainties was the worst possible mistake. He affirmed that his wisdom was limited to the awareness of his ignorance [Plato 360 BCa].
- Plato (4th century BC) examined "the illusion of knowledge", describing the path from ignorance to knowledge [Plato 360 BCb], as is shown in fig. 2.2: opinion[7] can be apprehended *via* perception or illusion and knowledge *via* reasoning and understanding [Allert 2002]. Therefore, an immediate certainty (or opinion) should be distinguished from reality, since it can have external appearances without being a fact [Plato 360 BCb].
- Carneades (2nd Century BC), a sceptic philosopher, affirms that there is no criterion to state with certainty the truth of a representation, "since representation, which should simultaneously reveal the condition of the subject and the reality of the external object, is often a source of error" [Brunschwig+ 2003]. Carneades also rejects reason, since it is based on sensation which may lead to error [Cicero 2007; Brunschwig+ 2003].

Uncertainty about knowledge

Thus, the notion of subjectivity emerged with the demonstration of the role of our representations in our judgments.

Dominance of religion in Middle Ages

After the development of several schools of thought in ancient Greece, during the Middle Ages, philosophy was overshadowed by religion in Europe. In the Middle East, Ghazali (1058-1111), the author of *The Incoherence of the Philosophers*, evoked doubts about the validity of knowledge. Ghazali points out two sources of knowledge: subjective and objective sources. Revelation and intuition shape subjective knowledge "without any objective help or means" [Khan 1976]. In 1095, Ghazali, through a spiritual crisis of doubt, opted for Sufism and subjective knowledge, explaining that "knowledge is completely subjective. It is neither the result of pure intelligence, nor dogmatism. It belongs to the heart as the superior organ"[8] [Jabre 1958].

[7] "An opinion is an incomplete holding-to-be-true based on insufficient grounds, from which I derive nothing" [Kant 2004].

[8] « Connaissance est d'une nature complètement subjective. Elle n'est ni le fruit de l'intelligence pure, ni de la dogmatique. Elle appartient au cœur comme l'organe supérieur aux autres organe. » (La notion de certitude selon Ghazali dans ses origines psychologiques et historiques [Jabre 1958]).

During the Renaissance, the history of certainty is deeply marked by the philosopher René Descartes (1596-1650) who considers mathematical certainty as absolute certainty [Descartes 1996], assuming that all phenomena should be explained in terms of mathematical reasoning [Descartes 1637].

Dominance of perfect rationality in Renaissance

The vision of Descartes continues to endure through the following centuries: "an intelligence which for a given instant knew all the forces by which nature is animated, and the respective situations of the existences which compose it;... nothing would be uncertain to it and the future as the past would be present to its eyes"[9] [Laplace 1986, translated by Pearson 1978][10].

Similarly, Lord Kelvin reduces scientific knowledge to something expressible in number: "in physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science, whatever the matter may be" [Kelvin 1891]. "This statement captures concisely the spirit of science in the 19th century: scientific knowledge should be expressed in precise numerical terms; imprecision and other types of uncertainty do not belong to science" [Klir 2005].

Scientific knowledge in the 19th century

However, some other philosophers have a different attitude in the face of uncertainty. They accept some limits in its treatment and admit that human beings do not answer all their questions by logic, mathematics, and physics:

- Blaise Pascal (1623-1662): "all that I know is, that I must soon die;... this only I know, that when I leave this world, I must either fall forever into nothingness, or into the hands of an incensed God..." [Pascal 1849],
- Emmanuel Kant (1724-1804): "no one, it is true, will be able to boast that he knows that there is a God and a future life;... No, my conviction is not *logical*, but *moral* certainty" [Kant 1855].

Limits of certainty in metaphysical questions

These metaphysical questions show some limits in the treatment of uncertainty. Subjective un/certainty is only recognized in metaphysical philosophy. In science, the emphasis is on objective certainty that aims to completely eliminate uncertainty, giving explanations and predictions for all phenomena. This mode of thinking had been dominant in science prior to the 20th century affirms Klir 2005, explaining that "while ordinary life without uncertainty is unimaginable, science without uncertainty was traditionally viewed as an ideal". Mechanic questions are answered thanks to the laws of Newton. In the late 19th century, Newton's laws reached their limits in the study of very small particles, such as electrons. Statistical mechanics were then used to study microscopic systems. Thus, uncertainty is recognized and studied as a *real*

Limits of certainty in particle physics

[9] Original statement in French: « une intelligence qui, à un instant donné, connaîtrait toutes les forces dont la nature est animée et la situation respective des êtres qui la compose embrasserait dans la même formule les mouvements des plus grands corps de l'univers et ceux du plus léger atome, rien ne serait incertain pour elle, et l'avenir, comme le passé, serait présent à ses yeux » [Laplace 1986].

[10] For more explanations see [Keuzenkamp 2000]. For the entire translation of Laplace's book see [Laplace+ 2007].

physics problem and "the negative attitude toward uncertainty was for the first time revised" [Klir 2005].

Later, in 1921, Frank Knight underlines "the fundamental difference between a determinate uncertainty or risk and an indeterminate, unmeasurable one" [Knight 1921][11]. This measurement, according to Knight, is the probability of occurrence of an event and this distinction extends the notion of uncertainty beyond probability, in theory. But it was not until the second half of the 20th century that uncertainty was liberated from "its probabilistic confines", thanks to two generalizations in mathematics [Klir 2005]: generalization of the classical measure theory [Hawkins 2001] and generalization of classical sets to fuzzy sets [Zadeh 1965].

As explained in section 2.1.1, uncertainty and decision come from the same root. There are also common points in their history. Before the 20th century, decision-making has a *perfect* image that supposes a "perfect rationality". This myth reached its end with "boundary rationality", presented by Simon 1955. The implicit hypotheses assumed by classical decision theories are [adapted from Simon 1955; Moscarola 1984; Tsoukiàs 2008]:

Implicit hypotheses of classical decision theories

- decision-makers know the problems, can formulate them, know all options and their consequences, and can process information with a "perfect rationality" to find an optimal" solution,
- information is available,
- the behavior of the environment is identifiable, regarding the consequences of each option.

Physiological limits of human organism

Simon questions these elements, specially the idea of perfect perception and rationality: "every human organism lives in an environment that generates millions of bits of new information each second, but the bottleneck of the perceptual apparatus certainly does not admit more than 1000 bits per second, and probably much less. Equally significant omissions occur in the processing that takes place when information reaches the brain" [Simon 1959][12].

Reason, emotion, and bias

The portrait of "rational man" is also blemished by bias in decision-making, as studied by Kahneman+ 1982[13], and the role of emotion in decision-making by neurologist Damasio 1994 who affirms: "I never wished to set emotion against reason, but rather to see emotion as at least assisting reason... nor did I ever oppose emotion to cognition since I view emotion as delivering cognitive information."

In sum, some scientists (such as Aristotle, Descartes, Laplace, Lord Kelvin) emphasize objective certainty based on a perfect reasoning that allows us to predict the state of (deterministic) systems in the future. Others (such as Socrates, Plato, Carneades, Ghazali, Pascal, Kant, Wittgenstein, Damasio, Simon, Tversky, Kahneman, Berthoz) evoke subjective certainty, based on an *imperfect* reasoning, affected by bias and emotion. After tracing the history of uncertainty through the centuries, to study delay in decision-making when faced with uncertainty, we need to know how it is defined today. In the next section, we see how uncertainty is precisely defined in dictionaries and in the recent literature.

[11] http://www.econlib.org/library/Knight/knRUP.html

[12] Tsoukiàs 2008 explains the impacts of the "radical" invention of Simon on "classic" decision theories and continues with two other major innovations, namely the works of Zadeh 1965 and Tversky 1967.

[13] Daniel Kahneman is a psychologist and winner of the 2002 Nobel prize for economics, fruit of a long-time collaboration with Amos Nathan Tversky, cognitive and mathematical psychologist.

Table 2.1: Two approaches to define uncertainty

Uncertainty in **object-based approach** is:

- a lack of information [Thiry 2002],
- a difference between required and available information [Galbraith 1973; Klir 2005],
- an attribute of information [Zadeh 2006],
- a lack of numerical probabilities of various outcomes [Knight 1921].

Uncertainty in **subject-based approach** is:

- a state of mind characterized by a conscious lack of knowledge [Head 1967],
- a sense of doubt, in the context of action, that blocks or delays action [Lipshitz+ 1997],
- an individual's perceived inability to predict something [Milliken 1987],
- an inability to act deterministically [Thompson 1967].

2.1.3 Two approaches to define uncertainty in the academic literature

To name things wrongly is to add to the misfortune of the world[14].
Albert Camus

We identify two aspects in definitions of uncertainty given by dictionaries: 1) "something that is not known"[15], 2) "the state of being uncertain"[16]. The first describes uncertainty through the state of an unknown object and the second through the state of an unsure subject.

Knight's definition

The most popular academic definition of uncertainty is probably given by the influential economist Knight 1921: a situation wherein it is not possible to specify numerical probabilities of various outcomes. Knight's definition is a *good* introduction to new mathematical theories to process uncertainty. It appeared in the second half of the 20th century (see section 2.1.2).

Risk and uncertainty

In the same definition, Knight 1921 specifies risk as a situation wherein the probabilities of outcomes can be known. The term risk is introduced, in 1907, by another economist, Irving Fisher, who proposes a reduction of each expected gain according to its risk [Buchanan+ 2006]. Therefore, historically, the notion of risk is associated with a probable loss. Knight 1921 affirms that "the word "risk" is ordinarily used in a loose way to refer to any sort of uncertainty viewed from the standpoint of the unfavorable contingency, and the term "uncertainty" similarly with reference to the favorable outcome; we speak of the "risk" of a loss, the "uncertainty" of a gain."

For Knight 1921, a determinate uncertainty is equal to risk. Similarly, "the area of incalculable risks[17] is thus marked by uncertainty. It is in this area of uncertainty that decision becomes a peculiar responsibility of an entrepreneur" [Dwivedi 2002]. Therefore, risk and uncertainty are a different degree of a same thing, namely "lack

[14] « Mal nommer les choses, c'est ajouter au malheur du monde. » – Œuvres complètes, tome 1, Paris, La Pléiade, p. 908

[15] http://dictionary.cambridge.org/dictionary/british/

[16] http://www.oxfordreference.com

[17] or opportunities, with the relatively new vision of uncertainty [Perminova+ 2008].

of information". Bouyssou+ 2006 give a clear explanation in this regard: there exist a wide range of situations of uncertainty, depending on the type of available information about the states of the world, between the two following extremes situations:

Range of uncertainty

- risk: a probabilizable uncertain situation *i.e.* there exists a unique probability distribution P on (S, A) that can be known objectively, where S is the set of possible states of the world and A is the subset of pertinent events for a problem[18],
- total uncertainty: a situation characterized by the absence of any information on events.

In this way, any new information helps in reducing uncertainty and "its conversion into a measured risk" [Knight 1921].

Some other definitions are more general, compared to Knight's one, emphasizing the lack of information in a more general sense than a probability:

- “uncertainty is an attribute of information” [Zadeh 2006],
- “the concepts of uncertainty and information are tightly interconnected. Uncertainty is viewed as a manifestation of some information deficiency, while information is viewed as the capacity to reduce uncertainty” [Klir 2005],
- uncertainty is the gap between the information required "to perform a task" and the available information [Galbraith 1973],
- “uncertainty is defined by the difference between the data required and the data already possessed; it is a "lack of information"” [Thiry 2002],
- uncertainty is to be unable to answer a question in a given context, because of *e.g.* lack, variability, or contradictory nature of information[19] [Dubois+ 2010b]. This definition takes into account the role of context.

The focus of some other definitions of uncertainty is not on information, its properties, or its availability. In these definitions, uncertainty is defined regarding an individual (an actor), through:

- a state of mind or a sense:
  - “in psychology, uncertainty denotes a state of mind characterized by doubt, or a conscious lack of knowledge about the outcome of an event” [Head 1967],
  - “uncertainty in the context of action is a sense of doubt” [Lipshitz+ 1997].
- its consequences on action:
  - uncertainty is “an individual’s perceived inability to predict something accurately” [Milliken 1987],
  - “uncertainty is the inability to act deterministically” [Thompson 1967].
  - uncertainty “blocks or delays action” [Lipshitz+ 1997].

[18] « Un ensemble S [est] appelé *ensemble des états de la nature* (ou *états du monde*), en identifiant les événements à des sous-ensembles de S. En fait, nous n’aurons pas besoin que de la sous-famille d’évènements ‘pertinents’ pour le problème posé et nous prendrons alors la plus petite σ-algèbre ou tribu A contenant cette sous-famille. » [Bouyssou+ 2006].

[19] « L’incertitude : ne pas pouvoir répondre à une question dans un contexte donné » [Dubois+ 2010b].

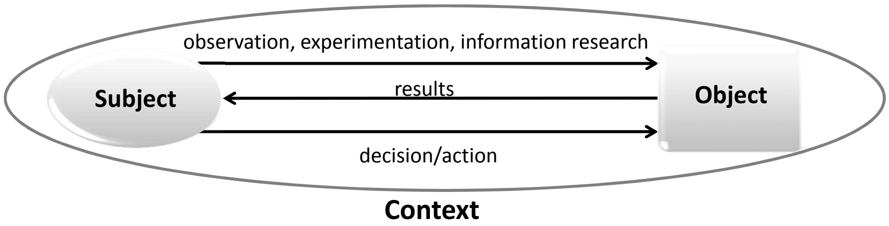


Figure 2.3: Definition of uncertainty

In the definitions mentioned, as with definitions given by dictionaries, we can identify two different aspects emphasized in economic and psychological approaches. Economists are interested in defining uncertainty in order to identify and control it. In the economic approach, definitions focus on the information about the state of an object or a situation that is unknown or evolves in time. The subjects (actors) are not clearly taken into account or are ignored in these definitions [Knight 1921; Galbraith 1973; Klir 2005; Thiry 2002]. In the same way, in mathematics and Artificial Intelligence (AI), uncertainty is considered as a property of information in order to model it [Zadeh 2006].

Psychologists aim to understand the functioning of the mind. In contrast to the decision-theory approach, "uncertainty is a psychological phenomenon existing only within the mind of the person who doubts". In the psychological approach, the focus is on the subject (actor). Uncertainty "is not a part of the external environment; such uncertainty may be a mental reaction to the external environment" [Head 1967].

A question arising from these approaches is: when a subject is uncertain about an object, where does the uncertainty come from? Is it in the subject's mind or does it come from the unpredictability of the behaviour of the object? Which of these aspects should be taken into account in the study of indecision under uncertainty? How can uncertainty be defined taking into account both object and subject? In the next section, we propose a more encompassing definition of uncertainty that brings together the object-based and subject-based approaches.

2.1.4 Defining uncertainty and structuring its influential factors

Uncertainty cannot be defined either as only pertaining to the subject or only to the object, because a subject could be uncertain about an object, while another subject was certain about it. Hence, uncertainty is a relationship between subject and object. Furthermore, context is an important factor in defining uncertainty.

A subject could be uncertain about an object but if he does not need to make a decision nor perform an action, this situation is not considered to be an uncertain situation. For example, I am not sure whether the laboratory building is accessible during the weekend or is closed due to construction, but since I do not plan to go there this weekend, this question does not concern me. I am in a situation of ignorance and not uncertainty.

To account for the considerations mentioned regarding the notion of uncertainty, its history, its etymology (its link with decision), and definitions in the literature, we define uncertainty as follows.

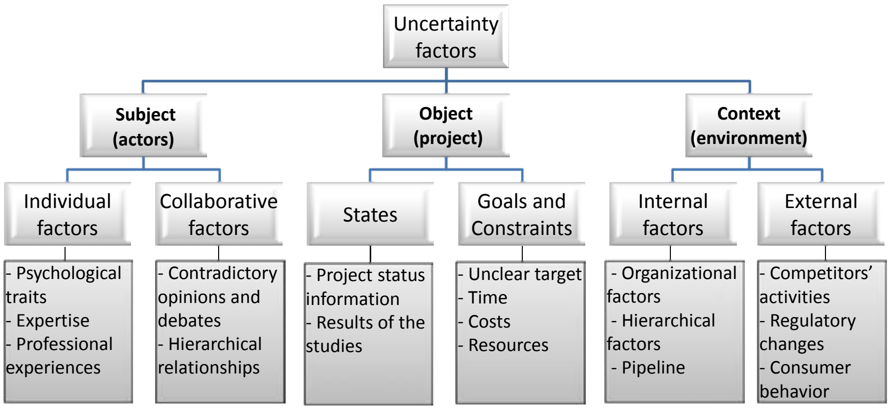


Figure 2.4: Typology of uncertainty factors

> *"Uncertainty is a subject's conscious lack of knowledge about an object, which is not yet clearly known, in a context requiring a decision (an action) within a certain time frame"* [Hassanzadeh+ 2012a].

This definition takes into account three elements that may generate, increase, process, and decrease uncertainty and contribute to its characterization and identification. In project management, these elements can be specified as follows:

1. **subject**: actor(s) who perceive and intend to act,
2. **object**: project that has an evolutionary state,
3. **context**: environment that includes the enterprise, the market, and society.

Based on this definition, we propose a typology for the factors that impact the generation, perception, and processing of uncertainty. The typology contains three main classes: object (the project), subject (a group of actors involved in the project), and context (the environment). This typology structures the factors that generate or affect uncertainty - and thus decision-making - in an organization (see fig. 2.4).

2.2 Indecision in its individual, collaborative, and organizational dimensions

"There is a large body of research on when and how we make decisions, but little on when and why we do not make them" [Brooks 2011].

Indecision / indecisiveness have been studied across several disciplines, from clinical psychology to vocational choice, marketing, and management [Potworowski 2010]. Both indecision and indecisiveness are used to describe decision latency, reluctance to decide [Rassin+ 2005a], and difficulty / inability to make decisions: "indecisiveness is an individual difference measure associated with chronic difficulty and delay in decision-making" [Frost+ 1993]. "Indecision is an inability to select a goal or, having selected a goal, to experience significant feelings of uncertainty about the goal" [Callanan+ 1990; Callanan+ 1992].

As for uncertainty factors (see section 2.1.4 on the previous page), the causes of uncertainty can be classified according to:

– subject: personality of decision-makers,
– object: quality and quantity of available information about an object or an event,
– context: conditions of decision-making.

Tables of appendix A show the examples of the causes[20] of indecision, mentioned in the literature[21], that we classify according to these three dimensions, which are detailed in the three following sections.

2.2.1 Causes of indecision relating to the subject

As Patalano+ 2011 affirm, the causes related to the actors (subjects) are mostly studied at an individual dimension. We distinguish three interrelated groups of individual causes (see tab. A.1 on page 174 in appendix), explained in the following sections.

2.2.1.1 Personality of decision-makers

Some causes of indecision are related to a deep level of a personality that does not "allow one to reach a decisional state of mind" to make a decision [Salomone 1982; Frost+ 1993], for example:

– low self-esteem [Effert+ 1989],
– low life satisfaction [Rassin+ 2005b],
– instability [Germeijs+ 2002] or not knowing what one wants [Frost+ 1993],
– tendency to consider the negative consequences of decision more harmful than negative consequences of inaction [Brooks 2011],
– responsibility avoidance [Janis+ 1977] or divestment of responsibility [Bacanli 2006],
– perfectionism [Frost+ 1993; Bacanli 2006], a maximizing tendency, especially in components of information search [Reed 1985; Schwartz+ 2002; Diab+ 2008],
– low competitiveness [Effert+ 1989].

Some other causes are related to our past.

2.2.1.2 Negative experiences of decision-makers

Experience of difficulty [Chartrand+ 1990] or negative experience [Elaydi 2006] may cause indecision. Duguay 2008 gives the example of the investors "paralyzed by indecision" because of the pain associated with loss in a negative stock market experience. The author explains that even though there is no reason that a new investment would provide the same result, losing money can be a "traumatic" experience after which it is hard to adopt a rational attitude. The painful memories

[20] These causes may be considered as symptoms of indecision, if they are repeated in a recognizable way.
[21] For more details, see [Potworowski 2010; Patalano+ 2011]

of negative experiences are often associated with (material / intangible) losses that may delay decision-making / acting in similar situations. Negative experiences and personality traits are interrelated and may reinforce and weaken each other.

2.2.1.3 Needs and emotions of decision-makers

As Damasio 1994 explains, emotion assists reason in decision-making (see section 2.1.2 on page 23). Emotions that may help us make decisions may become excessive in some circumstances and cause decision latency. In this section, we present an overview of needs and emotions, mentioned in the literature as causes of indecision. These needs and emotions, resulting from personality traits and negative experiences, may cause emotions that delay decision-making:

- hypersensitivity to threat [Rassin+ 2005a],
- inherent fear of (responsibility for) change [Rassin+ 2005a],
- fear of mistakes and missing opportunities [Bacanli 2006],
- doubt about the accuracy and completeness of the available information [Frost+ 1993],
- doubt about the pertinence of the eventually / selected alternative [adapted from Reed 1985],
- worry about the consequences of the decision (undesirable effects) [adapted from Germeijs+ 2002],
- lack of clarity as to what the worry is about [Germeijs+ 2002],
- post-decisional doubt / worry [Frost+ 1993],
- post-decisional regret about what would be lost (missing opportunities) [Germeijs+ 2002; Bacanli 2006],
- intolerance of uncertainty [Buhr+ 2002] or need for certainty [Bacanli 2006],
- difficulty and panic under time pressure [Bacanli 2006].

Difficulty and panic under time pressure is considered in both subject and context classes, since it depends on both the individual and the decision-making situation (see appendix A on page 173). Some individuals may be indecisive only under time pressure. According to Ferrari+ 1997, indecision is not associated with intelligence. The causes of indecision relating to the subject may be different in individual and collaborative cases within a group of decision-makers.

2.2.1.4 Group dynamic

Patalano+ 2011 indicate that little work has been carried out on individual indecision and group processes. This study presents an empirical examination of the relationship between indecision in individuals versus small groups of three people. The results show that the group process increases confidence and that individual indecision, even that of the most indecisive individuals, does not appear in the group and “might not be a critical factor in the composition of decision-making groups” [Patalano+ 2011]. It should be noted that this result concerns small groups of three people.

Charan 2001 underlines some causes of indecision relating to group dynamics: lone heroes and self-interest, misfiring in personal interactions, intimidation by the group dynamics of hierarchy. These elements may harm the dialogue within a group.

Freeman 1999 and Harris 2005 underline ambiguity of the responsibility as a disadvantage of collaborative decision-making that we consider as a possible cause of indecision in groups, especially when individuals have responsibility avoidance [Janis+ 1977] or divestment of responsibility [Bacanli 2006], leaving the decision to others (buck-passing) [Germeijs+ 2002].

Regardless of personalities and experiences of individuals and group processes, each decision-maker needs information about the object, events, and possible options to decide. The imperfection of this information and the quality of the options may cause decision latency.

2.2.2 Causes of indecision relating the object or events

2.2.2.1 Imperfection of information

Information is fundamental; it constrains and conditions each decision [Simon 1960; Pomerol+ 2008]. The role of quality, quantity, searching for and processing information in indecision is taken into account by the authors who work on indecision in psychology (see tab. A.3 on page 176 in appendix):

- difficulty in searching for information [Bacanli 2006],
- limits on the quantity and quality of information [Paivandy 2008] such as vagueness of information [Scheffler 1979],
- information processing in an inefficient manner [Chang 2007].

The limits on the quantity and quality of information are well studied in AI, to automatically process uncertain information, with no link to human indecision. To better understand the limits of information, we review the notion of imperfection of information in AI.

In the case of decision-making under uncertainty, the information available does not allow actors to answer questions on possible options and their consequences. This information is qualified as "imperfect"[22]. This imperfection may be of different natures in different forms.

Several typologies of imperfection of information are described by Tacnet 2009. The typologies mentioned by Tacnet 2009 are studied with a view to processing uncertainty. All of them consider uncertainty as a form of imperfection of information. We consider uncertainty as a result of the imperfection of information. We present an overview of different forms of imperfection of information that cause uncertainty and consequently may cause indecision:

- absence: information is totally unavailable,
- incompleteness: information is partially unavailable,
- contradiction (incoherence): existence of paradoxical information,
- noise: information is subject to random errors [Dubois+ 2001],

[22] Inspired by the description of Dubois+ 2010b, see section 2.1.3.

- bias: information is subject to systemic errors [Dubois+ 2001],
- imprecision: information is not exact,
- volatility: information can change rapidly,
- randomness: information is subject to "variability of observed repeatable natural phenomena" [Dubois+ 2010a],
- ambiguity: existence of multiple and conflicting interpretations for the same information [Thiry 2002],
- multidisciplinarity: information concerns multiple domains. Multidisciplinarity is not a defect in itself, but may make information difficult to understand,
- reliability: information whose source is not reliable,
- redundancy: existence of several forms for the same information. Redundancy is not always a defect and may makes information explicit [Dubois+ 2001],
- abundance: a great deal of information is available.

These imperfections and their degrees might be differently perceived by different actors according to their backgrounds, competences, preferences, etc. One reaction, in the face of uncertainty caused by these imperfections of information may be the postponement of the decision, especially when high investments are at stake.

It should be noted that, as Johansen 2007 states, "the dangers are characterized by volatility, uncertainty, complexity, and ambiguity. But these same dangers create leadership opportunities... in terms of vision, understanding, clarity, and agility."

Imperfection of information is not the only cause of indecision, caused by the object. The quality and quantity of options (choices, alternatives) influence decision-making.

2.2.2.2 Quality and quantity of possible options

In a decision-making process, possible options depend on the (evolutionary) state of an object (a project in the case of project management) and the outcomes of some events. Some causes of indecision may be related to the options:

- lack of option quality *i.e.* absence of a satisfactory option [Brooks 2011],
- lack of option clarity *i.e.* unclear or ambiguous options [Brooks 2011],
- conflict between equally attractive alternatives [Osipow+ 1976],
- not accepting that the options are equally desirable [Neumann+ 1944],
- option similarity, since decisions between similar options are difficult to make and also to justify to others [Brooks 2011],
- external barriers to preferred choices [Osipow+ 1976].

The external barriers are not inherent in choices but depend on the context of decision-making. Hence, the barriers are considered in both object (options) and context classes (see appendix A on page 173). In the same way, other elements of the organizational context may favor or not delay decision-making.

2.2.3 Causes of indecision relating to organizational context

In companies, other factors beyond individual and collaborative ones, namely those related to the organizational culture, may also play an important role in indecision.

An organization has its own culture and history, can be public or private, quoted on the stock market or not. These characteristics of an organization strongly affect its decision-making processes.

The problem of indecision as an organizational pathology is studied by Denis+ 2011 who label it "escalating indecision" or "network of indecision", a phenomenon in which people invest time and energy in decision processes without any clear result.

Davenport 2010 affirms that “very few organizations have undertaken systematic efforts to improve a variety of decisions” and consequently, there is a need for a systematic approach to improve a variety of decisions. Similarly, Denis+ 2011 indicate that little attention is given to indecision in the organizational literature.

In the following sections, we classify the causes of indecision relating to organizational context mentioned in some of the few existing studies [Charan 2001; Davenport 2010; Denis+ 2011]. Tab. A.3 on page 176, in appendix, shows the examples of the causes relating to organizational context.

2.2.3.1 Work environment

Charan 2001 points out some causes of indecision in organizations, that probably have their individual causes, which can grow in an *unhealthy* work environment *e.g.*:

- lack of intellectual honesty which harms open, honest, and decisive dialogue and decreases mutual trust,
- lack of trust to protect oneself in an unsafe environment,
- lack of conviction, meaning people “speak their lines woodenly”,
- lack of emotional commitment, meaning people do not perform planned actions decisively.

Charan 2001 affirms that "breaking a culture of indecision" requires a leader who can promote intellectual honesty and trust between people.

2.2.3.2 Leadership

Some causes of indecision relating to leadership are as follows:

- strategic ambiguity [Denis+ 2011],
- “pluralistic settings characterized by diffuse power and divergent interests and conceptions” [Denis+ 2011],
- lack of candid dialogue and lack of emotional fortitude in leaders [Charan 2001],
- lack of follow-through [Charan 2001],
- constraints of formality [Charan 2001],
- lack of closure[23] coupled with a lack of sanctions [Charan 2001].

More directly and specifically than the work environment and leadership issues, the process of decision-making may cause decision latency.

[23] “Closure means that at the end of the meeting, people know exactly what they are expected to do” [Charan 2001].

2.2.3.3 Status of decision and the process of decision-making

Davenport 2009 makes the criticism that decisions are generally considered as "the prerogative of individuals - usually senior executives" and “the process employed, the information used, the logic relied on, have been left up to them, in something of a black box. Information goes in, decisions come out and who knows what happens in between?” Only a few organizations have "reengineered" their decisions.

2.3 Conquering a culture of indecision

To “conquer a culture of indecision”, Charan 2001 proposes implementing an "organization’s social operating mechanisms"[24] that enable honest debate through which the work of shaping a decisive culture gets done. Such mechanisms include four characteristics:

1. openness, meaning that the outcome of the decision is not predetermined,
2. candor, meaning "willingness to speak the unspeakable",
3. informality to encourage candor,
4. closure, meaning that at the end of the meeting, everyone knows exactly what he is expected to do.

Charan 2001 underlines some other elements that can help: cross-functional collaboration, asking the right questions, identifying and resolving conflicts, creating mechanisms that encourage this open dialogue, speedy execution, appropriate follow-through and constructive feedback, and differentiating people with sanctions and rewards.

Davenport 2010 identifies 14 interventions that managers, mostly in IT functions, have employed to make better decisions: use of a rigorous statistical system, improving the integrity of data, changing the culture or leadership, trying to communicate the process and the results of a decision to affected parties, making changes in the decision-making process, educating decision-makers, etc.

[24] Social operating mechanisms are “the executive committee meetings, budget and strategy reviews, and other situations through which the people of a corporation do business” [Charan 2001].

Conclusion - part I

In this part, we have, in the first instance, seen that pharmaceutical R&D projects are risky, long-lasting and expensive projects composed of several phases of tests and studies on new compounds. At the end of each phase, the results of the tests are examined to make a Go / No Go decision, meaning to continue or to stop development. Go / No Go decisions are based on benefit-risk balances which are sometimes very difficult to assess, because of a high degree of uncertainty caused by imperfect information which becomes progressively more accurate. Additionally, Go / No Go decisions are made collaboratively by various experts who may perceive uncertain information differently.

In this context, decisions may either be deferred, because of the non-emergency of situations, or be invalidated *a posteriori*, since Go / No Go decisions are often reversible. However, the delay in decision-making may engender heavy consequences in terms of investments and also damage the image of the company. Moreover, as Denis+ 2011 argue, perpetual decision-making without decision outcomes consumes material and especially human resources. Beyond the dollar values, the considerable cost to individuals in terms of emotional stress and frustrated effort has to be taken into account.

Secondly, in order to better understand delay in decision-making when faced with uncertainty, we have examine the notion of uncertainty. Through an etymological study, we point out that uncertainty and decision have the same root and are tightly interconnected. We underline two approaches to defining uncertainty: object-based and subject-based approaches and propose an encompassing definition of uncertainty that brings together these approaches, since in the study of the causes of indecision under uncertainty, both causes relating to the object and those relating to the subject should be considered. Context and time are two other key elements of our definition.

Thirdly, the notion of indecision is reviewed. We classify some causes of indecision, mentioned in the literature, according to three dimensions:

– subject(s): the personality, negative experiences, needs and emotions of the decision-maker at an individual level, and group dynamics in collaborative decisions,
– object: the quality and quantity, search and processing of information about an object or an event and the available options,
– context: work environment, leadership, status of decision and the process applied to making decisions.

The four following points draw our attention:

1. contrary to decision and uncertainty, which have a history as old as the Antiquity, indecision is a more recent notion which is less widely considered in the literature: as an indication, the number of papers found with "Indecision" or "Indecisiveness" as keywords on the Science Direct website, on October 11th 2012, was only 35[25]. If "Business, Management and Accounting" is selected as "subject" in advanced research options, this number is reduced to 13. On the Springer website, the number of papers found for "Indecision" or "Indecisiveness" within title and abstract was 68. If "Business and Economics" is selected as "collection", this number is reduced to 4. On the Web of Knowledge website, 1064 papers were found in a search for "Indecision" or "Indecisiveness" in topic. If "Operations Research Management Science" and "Business Economics" are selected as "research areas", this number is reduced to 47,
2. among the causes of indecision, the role of personality is relatively well studied in psychology:
   - from 35 papers with indecision as a keyword found on the Science Direct website, 29 are in the field of psychology (selecting "Psychology" as "subject" in advanced research options),
   - from 68 papers found for "Indecision" or "Indecisiveness" within title and abstract on the Springer website, 31 are in "Humanities, Social Sciences and Law" and "Behavioral Science" collections,
   - from 1064 papers found on the Web of Knowledge website, searching for "Indecision" or "Indecisiveness" as a topic, 707 papers are in "Psychology", "Psychiatry", and "Behavioral Sciences",
3. limits on quality and quantity of information have been widely studied in AI [Dubois+ 2001; Bouyssou+ 2006; Dubois+ 2010b; Aven+ 2011],
4. as some recent research works indicate, the role of the organizational context is less widely considered in the literature [Davenport 2009; Davenport 2010; Denis+ 2011; Brooks 2011; Akdere 2011].

This bibliographical study confirms the importance of improving decision-making and the lack of studies about indecision in organizations. The studies mentioned propose areas for global improvement, but there is little explanation in detail about decision-making processes, the causes of delay, and the way these causes might be controlled. In this regard, we answer these questions in two next parts:

- why are some difficult Go / No Go decisions frequently delayed?
- what are the characteristics of delayed decisions?
- why are decisions not respected once made, or unmade and remade over time?
- what are the processes applied to making Go / No Go decisions?
- what are the current practices implemented by the actors to make collaborative decisions and are the current practices efficient or are some changes necessary to reduce delay?

[25] On the same day, on the Science Direct website, the number of papers found with "Decision" and "Uncertainty" as keywords were respectively 17,154 and 8,922.

Part II

Decision process modeling

Method, application, and results

Purpose: in complex industrial contexts, decision-making at a high level often requires the contribution of various actors to the information life cycle, from the production of the information to its consumption, the latter being the decision itself. This is true in the pharmaceutical industry. Although pharmaceutical projects are perfectly defined in terms of operational tasks, the information life cycle is not clearly defined. To diagnose the pathology of recurrent delay in difficult decisions, it is necessary to describe how information is transformed into decision. The purpose of this part is, first, to model the Go / No Go decision-making process, thus clarifying the information life cycle. This model is based on enterprise-engineering methods. It visualizes the contributions to this cycle of different actors, such as functional managers, project managers, and experts. We shall then focus on the last stage of this cycle *i.e.* collaborative decision-making, to understand how multidisciplinary experts perceive and evaluate various scientific and economic information in the process of coming to a decision. We detail this stage in a framework, through a fuzzy-based approach. This will help in understanding how a consensus is reached in a collaborative decision and why it is sometimes difficult to reach. A measure to quantify the risk of invalidating decisions is proposed, which is based on the acceptability of the collaborative decision by different experts.

Design/methodology/approach: a literature review, collaboration with an industrial partner, enterprise engineering methods, and a fuzzy-based approach are used to model the collaborative decision-making process in drug development projects.

Findings: the model of the collaborative decision-making process highlights the contribution of different actors to the information life cycle. The focus on the last

stage of this process illustrates the different perceptions, evaluations, and reasoning about the same information by different experts. Based on fuzzy inference rules, the behavior of each expert is modeled and a confidence index is defined to measure the risk of invalidating collaborative decisions *a posteriori*.

Research limitations: the framework that details the last stage of the collaborative decision-making process, as with all models that try to simulate human behaviors, makes several (simplifying) assumptions which inevitably influence its results.

Originality/value: drug development projects are already perfectly defined in the operational tasks of performing tests and producing information, respecting strictly regulatory measures. Little attention is given, however, to the activities in which the results are aggregated, prepared, and presented. Our model of the Go / No Go decision-making process takes into account the transformation of information before its transmission to decision-makers. Our framework for the last stage of this process models the behavior of different decision-makers and formalizes the differences in the cognitive processes they use to transform information into decision.

Introduction - part II

Information constrains and conditions each decision [Simon 1960; Pomerol+ 2008]. In pharmaceutical R&D projects, information about potential new medicines is progressively produced throughout different phases of the tests and studies in several fields, such as chemistry, pharmacology, toxicology, medicine, industrial production, regulation, law, economics, finance, marketing, etc. This information is then used by the experts in the different fields to assess the risk-benefit balances of the new compounds, taking into account their safety, efficacy, and quality, in order to make collaborative Go / No Go decisions[26]. The Go / No Go decisions are *easy* to make when the results are incontestably *good* or *bad*. In the other cases, when the results are uncertain for decision-makers, it can be difficult to make a collaborative decision. As the actors of the pharmaceutical industry point out, in these cases, Go / No Go decisions are frequently delayed or are sometimes made and then invalidated *a posteriori*.

In this context, the aim of our research, in this part, is to describe the activities that should be performed to generate and transform information into Go / No Go decisions, so as to find out when these decisions are delayed and why.

In chapter 3, the decision-making process is reviewed. Some decision-making processes are presented in general terms, to determine how information and decision are connected and to specify the main stages of a decision-making process. Modeling the Go / No Go decision-making process from the point of view of enterprise engineering helps visualize, describe, and analyze the Go / No Go decision-making process, taking into account the important aspects specific to enterprises that are mentioned in the literature. To achieve this objective, the notion of a model and the main steps of some modeling processes are reviewed. Some methods and modeling tools in enterprise engineering are then presented.

In chapter 4, our method of modeling, based on the CIMOSA reference architecture and using BPM notation, is presented. Simplifying and refining loops are clearly explained in this method.

In chapter 5, the proposed method of modeling is applied to Go / No Go decision-making processes: to investigate the problem of delay in difficult Go / No Go decisions, we model the Go / No Go decision-making process underlying the information life cycle from production to consumption (decision). This model is

[26] A Go / No Go decision determines whether the development of a compound should be continued or stopped in view of the available results about its safety, efficacy, and quality.

presented in three levels of detail where each level of detail answer some questions and raises some others.

First, Go / No Go decision-making is modeled in a macro vision that takes into account the different actors who collaborate in making Go / No Go decisions: those who generate and prepare information and those who consume it to make decisions. The information flow between them is also considered by the model. This macro vision of the model describes four macro stages in the Go / No Go decision-making process: the first three macro stages consist in searching for information and preparing decision-making. The last stage consists in making a choice, based on prepared information. An example based on the stability of a new compound illustrates the four macro stages. This macro vision takes into account the collaboration between actors who produce and prepare information and those who use it to decide. However, the activities of each stage are not detailed enough to study their possible dysfunctions.

Through the refining loop, a second level of detail in modeling is obtained wherein the activities of each macro stage of the decision-making process - their inputs and outputs - are illustrated. In pharmaceutical projects, the operational tasks to produce information, especially scientific parts that involve public health, are carefully described, respecting regulatory measures (descending information). Little attention is given to activities related to transforming this great deal of evolutionary information which is presented in a concise form to the experts who decide. The originality of our model is that the activities related to the preparation of information (ascending information) are also taken into account. But collaborative decision-making remains a black box at this level of the model. Since the purpose of this study is to investigate the causes of delay in decision-making, this "special" activity is detailed through another refining loop in a third (and last) level of detail.

The last stage of this process *i.e.* the collaborative Choice stage, is modeled in a framework. Its originality, compared to the models in the literature, is that it takes into account both "individual reflection" and "group interaction", aspects initially pointed out by Roy 1996. Based on fuzzy sets and fuzzy inference rules, this framework formalizes the individual information processing and decision-makers' interactions. It makes explicit the differences and similarities in the decision-makers' perceptions, evaluations, and reasoning. Finally, this framework leads us to define an index of decision invalidation that measures the risk of invalidating a decision made. It allows us to study previously invalidated decisions and predicts the behavior of the groups of decision-makers, depending on the inference rules used by individuals and groups.

This framework, focused on cognitive processes, does not give information about the practices of the actors who perform the activities of the decision-making process. But it can be used as a baseline to discuss and interview the actors about their practices. This is the subject of the next part (see part III on page 107).

3

Decision as a process

A decision is not an act, but a process.
Herbert Alexander Simon[1]

3.1 Decision-making process in the literature

Simon criticizes the images that "falsify decision by focusing on the final moment" and considers decision as a process [Simon 1960]. This change of attitude ends certain mythological or epic visions of decision, *i.e.* Julius Caesar crossing the Rubicon or De Gaulle launching the Concorde, and brings it back to the domain of scientific and systematic observation [Pomerol+ 2008]. Similarly, Roy 1996 explains that "the concept of a decision cannot be completely separated from that of a decision process. It will, therefore, be useful to think of the decision as unfolding within the framework of a process whose progress is punctuated by a certain number of critical points, one of which is the final action."

The English word process is from old French "proces", from the Latin *processus*, "process, advance, progress, go forward". In the mid-14th century it meant "course or method of action" and its main modern meaning is: "continuous series of actions meant to accomplish some result"[2]. This origin associates the notion of process with an expected result, a method, and a continuous series of actions. A process is a (partially) ordered sequence of steps, triggered by an event to reach a given goal. In this definition, the result is observable or quantifiable. As a decision is neither observable nor quantifiable, we extend this definition to include an intangible result [Vernadat 1996].

Etymology of process

Decision is also considered as a process by Colonel John Boyd, who studied the military decisions of US fighter pilots in the Korean War (1950-1953) and proposed a loop of four boxes to model these decisions: Observe, Orient, Decide, and Act (four box method or OODA loop, see fig. 3.1). The Observe stage involves collecting and communicating the information about the environment. The Orient stage consists in understanding and appreciating the situation and its possibilities. The Decide stage includes investigating responses to threats and opportunities, and determining an action, and finally, the Act stage is playing out the decision [Stenzel+ 2010].

Boyd's model

Similarly, Simon 1960 proposes an iterative decision-making process: Intelligence, Design, Choice, and Review (see fig. 3.2). The Intelligence stage as the first stage

Simon's model

[1] from Tsoukiàs 2008
[2] http://www.etymonline.com/index.php?term=process&allowed_in_frame=0

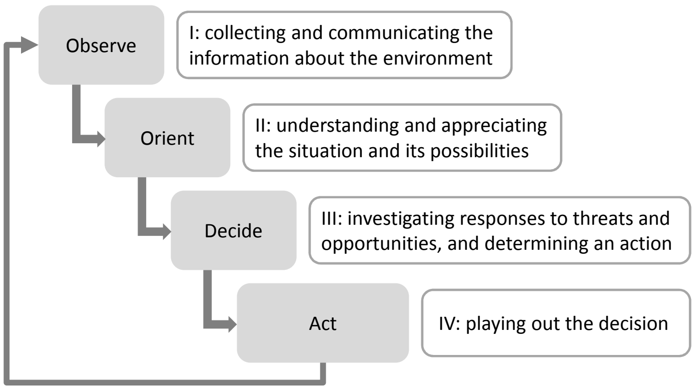


Figure 3.1: Boyd's four box method, based on the descriptions of Stenzel+ 2010

includes observation of reality, understanding of the problem, collection and understanding of information. The Design stage is composed of two sub-stages: identification of the criteria and construction of the alternatives. The first sub-stage focuses on identification and specification of the important criteria for decision, and measurement of the relationships between them. The second sub-stage focuses on identification, analysis, invention, development, and conceptualization of the alternatives. The Choice stage is what most people think of as making a decision [Forman+ 2001]. This stage focuses on the evaluation of the alternatives and development of the actions that satisfy the criteria of decision [Simon 1960]. The last stage is added by later researchers [Tweedale+ 2008]. The review implementation stage consists in weighing the consequences of the actions, gaining confidence in the decision, and planning actions.

Both the Boyd and Simon models are sequential, iterative, including a feedback loop. These models are similar in information collecting and processing, making a choice, and acting on information [Tweedale+ 2008]. The notion of communication appears in the Observe stage of Boyd's model, and evokes the notion of collaboration between actors. Additionally, Boyd emphasizes a fast appreciation of a situation and the need for agility in an "irregular, disorderly, unpredictable" world. Therefore, the collaborative aspect of war and its emergency and evolutionary context are reflected in the Boyd's model, while the Simon's model emphasizes identifying the problem, the criteria, and the alternatives. But none of these processes integrate new information that may complement available information or bring into question its accuracy.

The notion of new information is clearly taken into account in a "vigilant" decision-making process proposed by Janis+ 1977:

Janis and Mann's model

1. exploring possible options,
2. reviewing objectives to be fulfilled and personal values to be respected,
3. weighing up benefits and risks of each option,
4. searching new information relevant to choice,
5. assimilating new information,
6. re-examining the consequences of each option,
7. making provision for risks related to the chosen option.

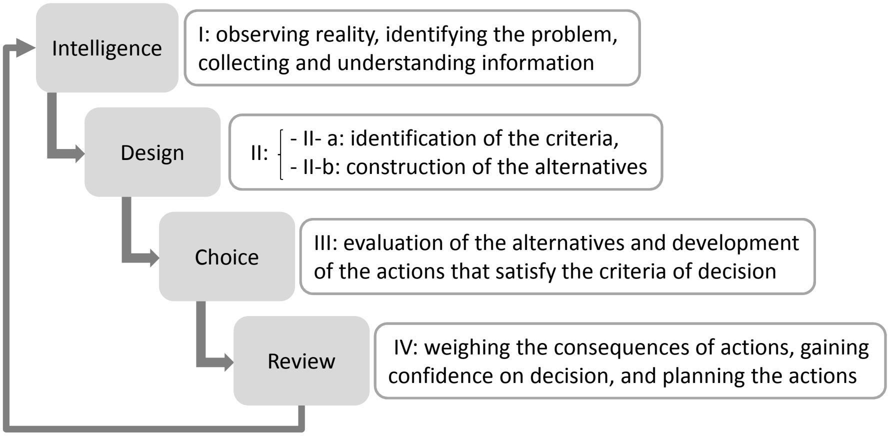


Figure 3.2: Simon's process [Simon 1960]

In this way, any new information or expert judgment to support the choice process should be taken into consideration, even if the new information invalidates the initial perception [adapted from Janis+ 1977 and Foskett 2001]. This model is particularly useful when information is imperfect[3] and becomes progressively more accurate.

The models mentioned consider decision as a process instead of an act, give a structure to decision, and connect information and decision. They allow us to study different activities that contribute to transforming a decision from information. They also help in studying the role of different actors in each stage, when decision is collaborative, as is usually the case in projects in enterprises[4].

In enterprises, decision-making involves various actors in the information life cycle. When decisions are frequently delayed, several questions arise: what are the activities that need to be performed to make decisions? Who contribute to these activities? What is the information flow between the actors throughout these activities? Which dysfunctions caused this delay? "Modeling is an essentially important way of exploring, studying, and understanding the world around us" [Gabor+ 2003]. A model of decision-making processes will highlight the sequence of activities[5], the contribution of each actor, and the flow of information. Such a model can be used to analyze the decision-making process and helps identify the problematical activities *i.e.* those that are delayed, in order to improve them. Enterprise engineering literature offers a wide range of methods and tools for process modeling. After reviewing the notion of a model, some methods and tools for modeling are briefly presented in the next section.

3.2 Process modeling to help decisions

"Better processes won't guarantee better decisions, of course, but they can make them more likely" [Davenport 2009]. Models can help "represent, understand, manage,

[3]A typology of imperfection of information is given in section 2.2.2 on page 33.
[4]An enterprise is defined as a "socio-economic organization" that makes profit from producing products or services [Vernadat 1996].
[5]Adopting the hierarchy of the activity theory, an activity is composed of actions or tasks, and an action is composed of operations [Leontjev 1978].

and improve complex processes" [Browning 2002]. Enterprise engineering provides industrial actors with enterprise models that help analyze, restructure, and improve the performance of enterprises [Vernadat 1996]. The purpose is to understand the functioning of an enterprise, either to help decision-making, or to improve operations [Hammer+ 1993]. The objective of our study in this part is the first of these, namely to improve the decision-making process in an enterprise, through modeling. In this section, first, some basic definitions of process modeling, mostly in enterprise engineering, are introduced. Secondly, the main steps of modeling are reviewed. Finally, some methods and tools to model processes are presented.

Models to improve processes

3.2.1 Model in enterprise engineering

3.2.1.1 Definitions of model

The concept of the model is widely used in various fields, such as mathematics, physics, computer science, engineering, human sciences, art, etc. There is no consensus to defining this "common denominator" concept [Deguil 2008]. We aim to model the decision-making process in enterprises wherein problems of delay in decision-making occur. Before defining a model in enterprise engineering, we shall review the definitions of a model in some other fields, highlighting thier different constituent elements and their different degrees of formalism.

Etymology of model

The word model comes from the Latin *modulus*, meaning "a small measure, standard". In the 1570s, it meant "likeness made to scale" and in the 1630s, "thing or person to be imitated"[6]. This origin shows that model is strongly connected to a relationship of likeness and imitation between two objects. These three elements, including two objects and their likeness relationship, are the basis of each model. The degree of likeness, degree of formalism, language, and form of models vary according to their purposes and their fields.

Mathematical models

The most formal model is a mathematical one, which can be defined as "a mathematical construct designed to study a particular real-world system or phenomenon" [Giordano+ 2008] or "a mathematical model is a mathematical interpretation of assumptions concerning real-world problems" and can be in the form of equations, inequalities, matrices [Albright 2011], graphs, topologies, etc. Apostel 1960 generalizes the concept of the mathematical model to non-formal sciences, through this definition: A is a model for B, if A neither directly nor indirectly interchanges with B and A can be used to obtain information about B.

Models to answers questions

In software modeling[7], "a model is a simplification of a system built with an intended goal in mind. The model should be able to answer questions in place of the actual system" [Bézivin+ 2001]. Notions of "goals" and "questions" are put in the centre in this definition. A similar definition, that proposed by Minsky 1968 in information processing, is adopted by Vernadat 1996 in enterprise engineering: "to an observer B, an object A' is a model for an object A to the extent that B can use A' to answer questions that interest him about A."

[6] http://www.etymonline.com/index.php?term=model&allowed_in_frame=0

[7] applied to Model Driven Architecture of Object Management Group (OMG/MDA®), see http://www.omg.org/mda/

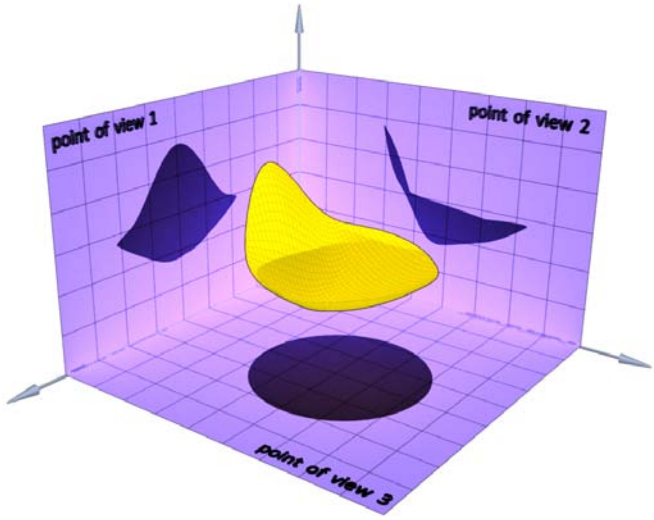


Figure 3.3: Different points of view for modeling, adapted from Deguil 2008

In the definitions mentioned, the starting point consists of the questions to be answered about a complex reality through a simpler (often visual) representation, called a model. Thus, a model should help knowledge acquisition of the reality represented, while not interchanging with it. In sum, a model:

Characteristics of a model

- is "inherently **purposive**" [Gluck+ 2005] *e.g.* description, visualization [Browning 2002], analysis, simulation, calculation (solution, maximization, estimation [Fischer+ 2009], prediction about some aspects of a phenomenon [Gluck+ 2005], or the behavior of a system,
- is from a **point of view** that, as its name indicates, can be defined as a particular perception of something to be modeled, an enterprise for example, which highlights certain aspects of it and makes the others transparent [Darras 2004] (see fig. 3.3),
- has a **scope** that limits its range, meaning "domain covered by the model, also called the universe of discourse" [Ross+ 1977], in order to "make the problem manageable" [Albright 2011],
- is expressed in a form or **representation language** with a **syntax**, a **semantic** and a degree of **formalism** [Vernadat 1998],
- has a **detail level**, *i.e.* the level of precision or granularity [Ross+ 1977].

3.2.1.2 Typology of models

Models can be classified according to several perspectives, depending on their properties or purposes:

- **structural, functional, and behavioral models**: a structural model[8] represents the architecture of a system, a functional model[9] describes the operations

[8] such as UML class/object diagrams [Atkinson 2002]
[9] such as operation specifications [Atkinson 2002]

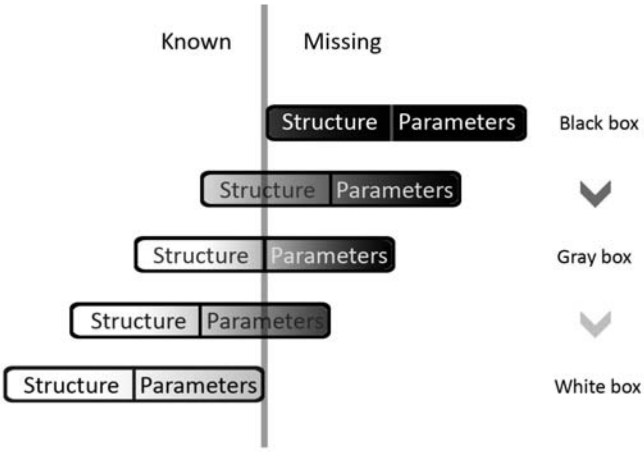


Figure 3.4: Black, gray, and white box models where the "darkness" of the model depends on the missing information [Gabor+ 2003]

of a system, and a behavioral model[10] predicts how a system behaves, responding to stimuli [adapted from Atkinson 2002]. Functional models can be divided into two groups:

- **function-based and process-based models**: the central constructs of these models are respectively function and process. Function-based models[11] use only one basic construct, meaning function (activity) at all levels of the model. Hierarchical functional decompositions are used to "map the organizational boundaries". In process-based models[12], processes as "ways of chaining activities" are modeled with no consideration of the "organizational boundaries" of the enterprise [Vernadat 1996],

- **analytic and systemic models**: analytic models decompose the studied problem into several simpler problems, while systemic ones consider “a system in its totality, its complexity, and its own dynamics” [Rosnay 1979]. Analytic and systemic models can be the bases of two different analysis approaches of the same names. A systemic approach reasons that “behavior is serial, not a mere succession. It can be resolved - it must be - into discrete acts, but no act can be understood in isolation from the series to which it belongs” [Dewey 2008]. The analytic approach is “understanding by taking apart” [Wilson+ 2010]. Tab. 3.1 compares these two approaches of analysis. According to Le Moigne 1990, the analytic approach is appropriate to resolve complicated problems and the systemic approach is suitable for complex ones[13]. The analytic approach is one- discipline-oriented and concentrates on detailed information about one

[10]such as UML statechart diagram [Atkinson 2002]
[11]such as SADT and IDEF methods
[12]such as CIMOSA, Petri nets
[13]A simple system has few component parts that are linked by a small number of rules [Simpson 2011]. A complicated system has many more component parts, related by more numerous and more inter-related rules [Simpson 2011], which can be studied separately and be reassembled without damage. A complex system also has numerous component parts that may be "less clearly defined" [Simpson 2011] and that lack meaning if they are separated from each other [Gianfranco+ 2010]. “A motor could be considered complicated, but a human being is complex” [Gianfranco+ 2010].

isolated variable at a time. It studies the nature of simple linear interactions, independent of duration. The analytic approach provides precise and detailed models, that are less useful in actual operation, such as econometric models. The systemic approach is multidisciplinary, taking into account global information on the effects of non-linear interactions within a group of variables, over time. The systemic approach gives insufficiently rigorous models to be useful in decision and action [Rosnay 1979],

– **black box, gray box, and white box models**: as fig. 3.4 shows, the structure and parameters of a black box model are not known. In a gray box model, the structure is known but the parameters are not known. In a white box model, both structure and parameters are known [Gabor+ 2003],
– **formal, semi-formal, and informal models**: formal models are expressed in "well-defined language with precise, mathematical semantics in terms of set theory, for example[14]" [Meyer+ 2000]. Formal models describe modeled objects through accurate, precise, unambiguous information [Schürr+ 2009]. One example of a semi-formal model is standard graphical notations [Vernadat 1998]. Informal ones are expressed in natural language [Vernadat 1998] and are characterized by "rich sets of objects and relations", giving "overviews and initial understanding" [Schürr+ 2009]. Informal models are "ambiguous" and "vague" and can be used for discussion or documentation [Aalst 2011],
– **static and dynamic models**: time is not taken into account in static models, while dynamic models include time as one of their variables [Anderton 1977],
– **deterministic and stochastic[15] models**: "uncontrollable" input values are respectively known / unknown, in advance, in deterministic / stochastic models [Anderson+ 2012].

3.2.2 Key principles of modeling

Gabor+ 2003 outline three key principles that have to be considered in system modeling: separation, selection, and parsimony. Separation means determining the boundaries between the system to be modeled and the rest of the world (meaning defining the scope of the model, see section 3.2.1.1). Selection means determining "certain essential aspects of a system" to be considered in the model. All interactions between the components of the system and those between the system and its environment cannot be taken into account. The notion of "aspect" is tied into "point of view" (see section 3.2.1.1). Points of view take the names of the aspects that they cover[16]. Parsimony means that in modeling it is preferable to create "as simple model as possible"[17]. "This means that a model is always imperfect, it is a

[14] Other examples of formal languages are first- order logic, computer languages [Vernadat 1998], description logic, etc.

[15] From Greek, *stokhastikos*, the sense of "randomly determined" is first recorded for German stochastik in 1934, see http://www.etymonline.com/index.php?allowed_in_frame=0&search=Stochastic&searchmode=none.

[16] These two notions, namely point of view and aspect, are sometimes used interchangeably in the literature, *e.g.*: to model a system, following the MECI method, a formalism is developed in four "points of view or aspects" [Darras 2004].

[17] The parsimony principle is also known as simplicity principle or Occam's (or Ockham's) razor: "if theory T is simpler than theory T^*, then it is rational (other things being equal) to believe T

Table 3.1: Analytic approach versus systemic approach, mainly adapted from Rosnay 1979 and also Le Moigne 1990; Salomon+ 2006

	Analytic approach	**Systemic approach**
Type of problem	complicated (decomposable)	complex (cannot be reduced to its components)
Scope of study	deep	broad
Nature of the study	discipline-oriented	multidisciplinary
Object of the study	one variable at a time	groups of variables simultaneously
Relationship between variables	changes in one variable leave others unchanged	changes in one "important" variable change the whole configuration
Subject of the study	nature of interaction	effects of interactions
Time	remains independent of time; the phenomena considered are reversible	integrate duration of time and irreversibility
Appropriation of the study	interactions are linear and weak	interactions are non-linear and strong
Method	isolation, concentration on each element	unification, concentration on the interactions between elements
Type of perception	precision of details	global perception
Type of information/ knowledge	detailed information, poorly defined goals	knowledge of goals, fuzzy details
Type of model	precise and detailed models that are less useful in actual operation	models that are insufficiently rigorous to be used as bases of knowledge but are useful in decision and action
Type of results	action programmed in detail	action through objectives
Validation	by means of experimental proof within the body of a theory	by comparing of the behavior of the model with reality

simplified representation of a system, it only approximates a system" [Gabor+ 2003]. Consequently, a model may differentiate from reality by:

Difference of model and reality

- its limited scope: *e.g.* taking into account only a segment of a supply chain,
- the elements that are not taken into account in its defined scope: *e.g.* taking into account only some elements[18] of this segment,
- its level of detail: *e.g.* taking into account only some properties of the selected elements.

These limitations simplify construction and manipulation of models, especially when the questions to be answered concern only a part of this reality or the reality to be modeled is very complex. Thus, choices of scope, elements, and detail level depend on the purpose of the model and its intended level of complexity. Kreimeyer+ 2011 warn against the errors that can be induced by these choices, since an element relevant to the purpose can be ignored in an "unclean" model. To decrease the errors induced by ignoring a relevant aspect in a model, we can take into account significant aspects of enterprises found in the literature.

Enterprise engineering literature offers a scope of enterprise modeling which includes five "basic aspects to be modeled in an enterprise" [Curtis+ 1992; Vernadat 1996]:

Scope of enterprise modeling

1. **what - functional aspects - object**: operations performed and object processed,
2. **what - informational aspects - object**: data produced and used,
3. **how - behavioral aspects**: way activities are carried out *i.e.* practices,
4. **when - organizational aspects - time**: time related to events that change the state of the enterprise,
5. **who - organizational aspects - subject**: resources.

On the one hand, these aspects cover important facets of an enterprise and on the other hand, our research questions *i.e.* the role of each aspect in the problem of delay in decision-making (see section 2.3 on page 37). In the next section, some methods and tools of process modeling are reviewed with a view to choosing those that enable us to investigate these aspects.

3.2.3 Steps of modeling

A modeling process is a "set of activities" to be performed in order to construct a model of something, with the purpose of "representation, communication, analysis, design or synthesis, decision-making, or control" [Vernadat 1996]. In the literature, the steps of modeling are *often* described through mathematical approaches either in mathematics [Giordano+ 2008; Albright 2011] or in other fields such as system identification [Gabor+ 2003], environmental systems [Ford 2009], etc.

Gabor+ 2003, in their paper on neural networks in system identification, distinguish some main steps in "all modeling": defining the goal of modeling, collecting

rather than T^*" (Stanford Encyclopedia of Philosophy, Principal Editor: Edward N. Zalta, available in `http://plato.stanford.edu/entries/simplicity/`).

[18] In mathematical modeling, some variables may be aggregated, considered constant, neglected, or their relationships might be ignored in order to simplify the model [Giordano+ 2008].

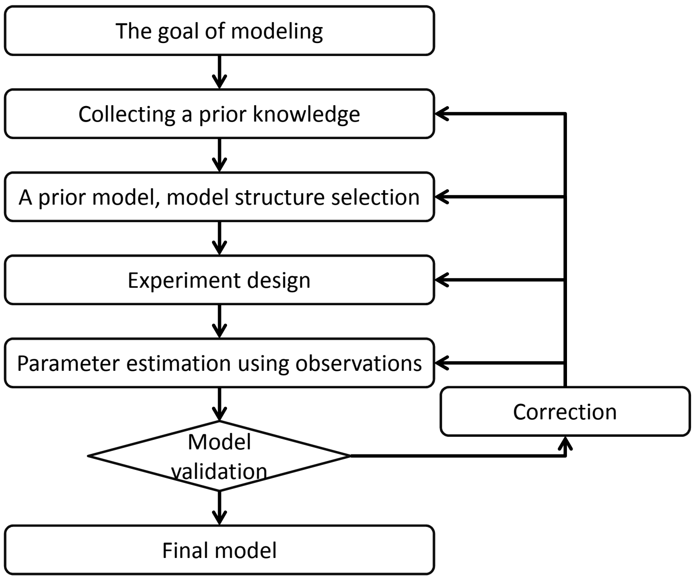


Figure 3.5: Iterative nature of modeling [Gabor+ 2003]

prior knowledge, selecting the structure of the model (white, gray, or black box model depending on available information, see fig. 3.4), designing and collecting information (design of the "circumstances of input-output data"), estimating the parameters of the model (relationships between inputs and outputs), validating the model (determining if the model serves its purposes or whether correction is necessary). The iterative aspect of modeling is illustrated in this description (see fig. 3.5).

Giordano+ 2008 [19] propose a similar modeling process, but clearly taking into account simplification and refining loops[20]: if the modeler cannot formulate or solve a model, it should be simplified, and if the results are not precise enough to answer the research questions, the model should be refined (see fig. 3.6).

Ford 2009 presents 8 steps of modeling which include both qualitative and quantitative modeling progressively. Fig. 3.7 illustrates these steps. “The first four steps are conceptual and qualitative in nature.” A wall separates the qualitative and quantitative parts of this modeling process. As Ford 2009 explains, some modelers prefer concepts and interrelationships within a systems, arguing that “parameter estimation and computer simulation are too difficult and too time-consuming.” Others prefer to make sense of the numbers, arguing that “qualitative discussions need to be tested through computer simulation. The major environmental problems of our day involve complicated dynamics that cannot be simulated in our head.” We agree with this argument for environmental problems, however it is very difficult (if not impossible) to quantify problems which involve a strong human component with all its complexity.

[19] Giordano+ 2008 also point out the similarity between mathematical modeling processes and 6 steps of “the **scientific method** as follows: 1) make some general observations of a phenomenon, 2) formulate a hypothesis about the phenomenon, 3) develop a method to test the hypothesis, 4) gather data to use in the test, 5) test the hypothesis using the data, 5) confirm or deny the hypothesis.”

[20] Simplification is explained in section 3.2.2 through separation, selection, and parsimony principles [Gabor+ 2003]. Refining is obtained by "the opposite way to simplification" such as expanding the scope of the model [Giordano+ 2008].

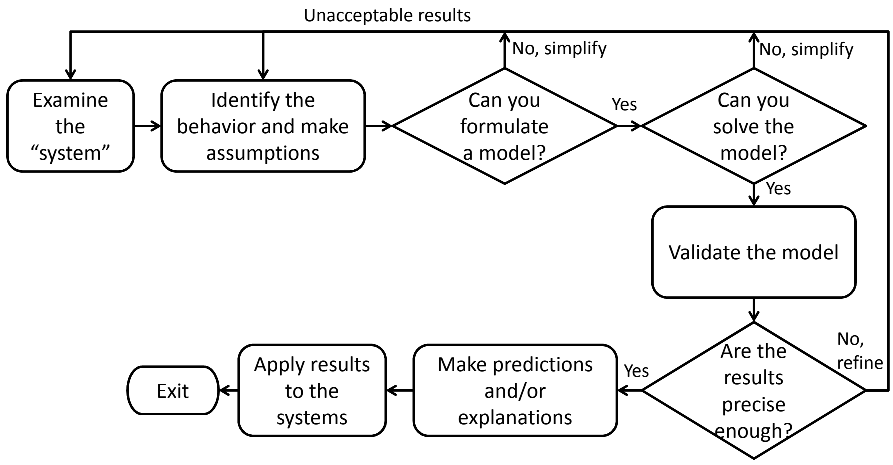


Figure 3.6: Simplifying and refining loops in modeling [Giordano+ 2008]

A more complete description of the modeling process is given by Albright 2011 who describes 8 steps of mathematical modeling, as follows:

- **step 1**: "state the question to be answered." At first, questions are narrow enough in order to manage the problem. Further questions can later arise from the knowledge obtained,
- **step 2**: "select the modeling approach." This step can begin with "some simple observations". The form of the model is determined, depending on observations and "the nature of assumptions".
- **step 3**: "define variables and parameters." Variables are the "quantities" that can change within a problem and parameters those that remain constant within a problem,
- **step 4**: "state the assumptions" in four categories:
  - to simplify the model,
  - to choose variables that are taken into account in the model,
  - to establish relationships between variables,
  - to determine the values of parameters,
- **step 5**: "formulate the model." As Albright 2011 considers "this is where the "mathematics" starts." Mathematical notions are used to describe observed data in order to find a pattern, such as an equation.
- **step 6**: "solve the model and state the solution." Solving an equation, constructing a graph, running a simulation, describing the behavior of the model are some examples of solving the model.
- **step 7**: "verify the model" to check the "reasonableness" of the assumptions, by comparing the information obtained through the model to the values calculated in real world,
- **step 8**: "refine the model." Refining a model means to improve it in some way, through additional observations or data, for example by[21]:
  - adding variables, parameters, or relationships between them that are intentionally ignored in step 3 [Albright 2011; Giordano+ 2008],

[21] In this list, items mentioned by Albright 2011 are enriched by those mentioned by Giordano+ 2008.

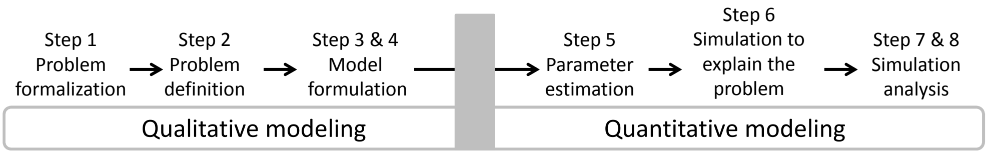


Figure 3.7: Qualitative and quantitative modeling [Ford 2009]

- allowing variation in the variables that were considered as constant for simplification purposes [Giordano+ 2008],
- reducing the number of assumptions [Giordano+ 2008],
- expanding the problem [Giordano+ 2008],
- generalizing the model to cover the similar problems [Albright 2011].

In the modeling processes mentioned, as in the definitions of a model (see section 3.2.1.1), the starting point is a problem or the questions to be answered about a phenomenon or a system. The next main steps include knowledge acquisition about the problem, construction, testing, correction and validation of the model, and finally, knowledge production. These are the common steps of these approaches. Their differences are in their focus and clarity in certain steps. Gabor+ 2003 explicitly consider knowledge acquisition. Albright 2011 connects the selection of a modeling approach to the nature of the assumptions made. Giordano+ 2008 describe both simplifying and refining loops. These modeling processes are used, in the following chapters, to construct our model. Since we aim to model the decision-making process in enterprises to investigate the problem of delay, in the next section some methods and tools of enterprise modeling are reviewed.

3.3 Methods and tools of process modeling in enterprise engineering

Methods and tools for enterprise modeling have appeared since the late 70's - early 80's. In the early 90's, the sharing of representative frameworks between different industrial actors, using enterprise modeling, became a general trend. Several methods, techniques, languages, notations, and architectures for process modeling were subsequently proposed [Vernadat 1996]. We briefly[22] review some of these methods, so as to adopt one that enables us to investigate the problem of delay in collaborative decision-making in enterprises. Our research questions, presented in section 2.3 on page 37, will guide our choice.

First, two reference architectures[23] are presented. These architectures consider different aspects (facets) of enterprises from different points of view[24]. Some modeling methods, languages, and notations will then be presented with a view to implementing these aspects.

[22] These methods are described by Vernadat 1996 and are compared by Darras 2004 and Ferchichi 2008 who give rich syntheses in their theses.

[23] An architecture is a set of components that are related together and construct a "whole defined by its functionality" [Vernadat 1996].

[24] As defined in section 3.2.1.1 on page 46, a point of view is a particular perception of an enterprise which highlights certain aspects of it and makes the others transparent [Darras 2004]. Points of view take the names of the aspects that they cover.

3.3.1 Zachman™, a framework for information systems architecture

The Zachman framework[25] is a "framework for information systems architecture" [Zachman 1987] for "identifying and disciplining the various perspectives involved in an enterprise architecture" [McGovern 2004]. These perspectives are presented in a 6 x 6 "matrix" with Communication Interrogatives as columns and Reification Transformations as rows. Communication Interrogatives consist of 6 areas to be considered: What (Structure), How (Activities), When (Time), Who (People), Where (Localisations), and Why (Motivation). Reification Transformations consist of 6 perspectives: Scope contexts (scope identification lists), Business concepts (business definition models), System logic (system representation models), Technology physics (technology specification models), Tool components (tool configuration models), and Operations instances (implementations). The descriptive representations constituted by this matrix are "relevant for describing something... anything: in particular an enterprise" [Zachman 2008; Salvendy 2001].

Zachman 1987 considers his framework valuable to improve professional communications within the information systems. It relates a variety of tools and methodologies. It helps to rethink, in an organized way, "the nature of the classic *application development process* as we know it today". However, “the Zachman framework is not capable of being directly implemented into an information system and the relationships between the description fields are not entered systematically. Furthermore, the relationship of Zachman’s framework with the specific creation of output within the business process is not apparent” [Salvendy 2001].

3.3.2 CIMOSA, an enterprise reference architecture

Computer Integrated Manufacturing Open System Architecture (CIMOSA[26]) [AMICE 1993] is an enterprise reference architecture[27] to construct and analyze production systems. CIMOSA is proposed by the European Computer Integrated Manufacturing Architecture (AMICE), within the European Strategic Program on Research in Information Technology (ESPRIT) [Vernadat 1998].

CIMOSA includes three axes: instantiation, derivation, and generation. The instantiation axis consists of three levels: generic, partial, and particular levels. At generic level, the basic constructs of modeling language are defined. Partial level includes partial models, *i.e.* pre-defined and reusable structures for a given application field. Particular level corresponds to specific models of an enterprise. Generic and partial levels constitute the CIMOSA reference architecture (subject to normalization) and the particular level corresponds to the particular architecture of a given enterprise (developed for special needs).

[25] “The Zachman™ Framework IS NOT a methodology for creating the implementation (an instantiation) of the object. The Framework IS the ontology for describing the Enterprise. The Framework (ontology) is a STRUCTURE whereas a methodology is a PROCESS. A Structure is NOT a Process. A Structure establishes definition whereas a Process provides Transformation” [Zachman 2008]. See the site of the Zachman Institute for Framework Advancement (ZIFA) on http://www.zifa.com/

[26] CIMOSA is the basis of European Pre-standard ENV 40003 now published as a joint European and ISO standard norm known as EN/ISO 19439 [Lillehagen+ 2008].

[27] “A reference architecture for a given domain is a generic architecture from which other architectures can be compared or derived” [Vernadat 1996].

The derivation axis comprises three description levels in conception: requirements definition, design specification, and implementation description [Vernadat 1996; Salvendy 2001].

The generation axis covers four aspects of enterprise modeling [Vernadat 1998]:

Generation axis of CIMOSA

1. function view (object): to describe the functionality and behavior of an enterprise in terms of processes, activities and operations *i.e.* what is to be done,
2. information view (object): to describe the objects of an enterprise, their relationships and their possible states *i.e.* which objects are treated and how they are managed,
3. resource view (subject): to describe the resources needed to perform operations, their roles and their management *i.e.* who does what, when and how,
4. organization view (context): to describe hierarchical relations and responsibilities *i.e.* who is responsible for what.

Enterprise modeling, using CIMOSA, passes through the following steps [Vernadat 1998; Darras 2004] :

Steps of CIMOSA

1. analysis of the functional business areas of the enterprise and their relationships,
2. identification of the processes to be modeled,
3. detailed analysis of the processes in terms of events, sub-processes, activities, etc.,
4. consolidation of the model through design specifications *i.e.* to describe each activity in terms of its inputs, its functional operations, resources, and sequence of activities,
5. adaptation of the model to implementation constraints,
6. the translation model in the language of systems used.

In complex industrial contexts, these multiple points of view make it possible: first, to filter some aspects of the enterprise, in order to temporarily concentrate on one aspect, then to study relations between different aspects.

3.3.3 IDEF modeling languages

Among the first works to appear on the subject of modeling was the Integrated Computer Aided Manufacturing (ICAM) program, which was developed for the US Air Force [Vernadat 1996]. The ICAM program aimed to increase manufacturing productivity by application of computer technology [Zhao+ 2011]. At that time, the ICAM program had identified the need for better technical analysis and communication for people who worked on improving productivity [Darras 2004]. The ICAM DEFinition (IDEF) modeling languages were produced to analyze and communicate the functional aspect of systems [Lakhoua+ 2011]. These languages were based on Structured Analysis Design Technique (SADT) [Vernadat 1996] and are primarily used for modeling the functional point of view [Darras 2004].

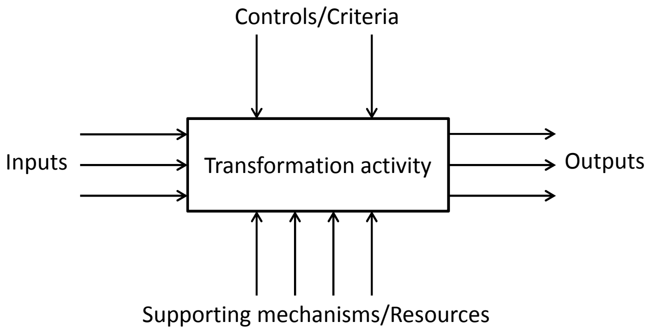


Figure 3.8: Syntax of SADT diagrams

The syntax of IDEF is largely graphical [Rouse+ 2007]. A model produced in IDEF consists of a set of box graphical forms, representing functions, that are linked by arrows [Jaulent 1992], representing inputs, outputs, controls, and mechanisms (see fig. 3.8).

The IDEF family of languages includes modeling languages such as IDEF0, through to IDEF14. IDEF0 was not developed to communicate relationships between functions, "it has no way of specifying a recipe or process, nor descriptions of the specific logic or timing associated with functions" [Rouse+ 2007]. IDEF1 is designed to produce models that integrate information in an enterprise. IDEF1 offers a set of rules and procedures to create an informational model [Darras 2004]. The notions of entity, relation, data base are then developed in IDEF1 [Ferchichi 2008]. Other languages of the IDEF family are designed to model different aspects of complex systems by simulation modeling, data modeling, process description capture, etc. [Darras 2004].

3.3.4 GRAI modeling method

Graph with Results and Actions Interrelated (GRAI)[28] is a modeling method that focuses on the decision system of an enterprise to improve its performance [Roboam 1993]. The GRAI method was developed at the University of Bordeaux in the early 80's [Ferchichi 2008].

Models built by this method use a grid, called the GRAI grid, which represents "the points where decisions are made (decision centres[29])" and the information relationships between these centers, in order to analysis and design the way decisions are synchronised in the enterprise [Doumeingts+ 2006]. The GRAI grid (see fig. 3.9) is a table including types of decisions and information needed over distinct horizons[30] and periods[31], "from near term operational to long term strategic". The rows and the columns respectively correspond to horizons and to types of activities or functions [Rouse+ 2007].

[28] Graphes à Résultats et Activités Interreliés (GRAI) a été développé à l'origine par le groupe de recherche GRAI du Laboratoire d'Automatique et de Productique de l'Université Bordeaux 1 [Ferchichi 2008].

[29] "Decision centres are the locations where decisions are made about the various objectives and goals that the system must reach and about the means available to operate consistently with these objectives and goals" [Doumeingts+ 2006].

[30] "A horizon is the part of the future taken into account by a decision" [Doumeingts+ 2006].

[31] "A period is the time that passes after a decision when this decision must be re-evaluated" [Doumeingts+ 2006].

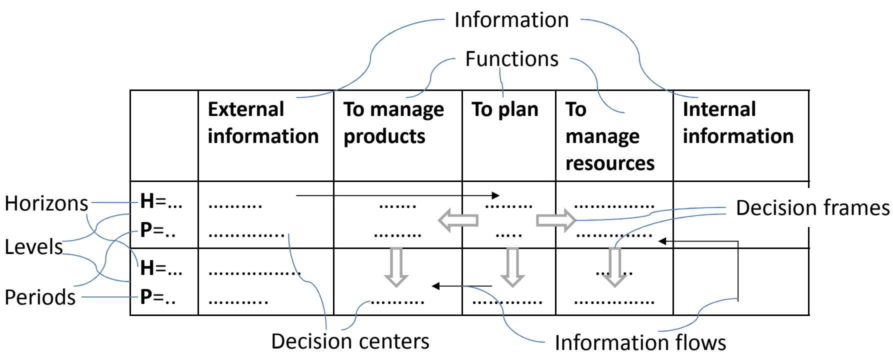


Figure 3.9: Concepts of the GRAI grid [Doumeingts+ 2006]

The GRAI grid offers a "one-page summary of the architecture of a decision-making system, providing an overview in a way no other technique matches." In this macroscopic, schematic representation, decisions are classified according to period and horizon. The grid makes it easy to distinguish operational, tactical, and strategic decisions. One disadvantage of the GRAI method is the lack of a rigorous methodology to construct a GRAI grid [Browne+ 1995].

3.3.5 OLYMPIOS model

The OLYMPIOS model is "an algebraic specification for modeling the information system of a manufacturing enterprise" [Haurat+ 1993]. The purpose of the OLYMPIOS model is to construct the information system (IS) for a given operator (a user, supplier, customer,...) of an enterprise. It focusses on the stages of the life cycle of an IS: specification, design, implementation, validation, and maintenance [Braesch 2002]. The OLYMPIOS model is based on abstract data types and algebras[32]. Its implementation and maintenance are made in conventional programming languages such as C++ [Darras 2004].

3.3.6 MECI modeling method

MECI[33] is a method to analyze and design the complex systems of enterprises [Pourcel+ 2002]. MECI was developed for the AICOSCOP[34] project [Bennour 2004]. The MECI modeling method consist of three steps:

- identifying the system to be modeled: identification of the key processes and the primary industrial objects,
- decomposing the system: the decomposition of the main processes into sub-processes or activities, defining objects related to the activities and industrial processes,
- identifying and characterizing the activities of the processes: the identification and specification of the activities and objects.

[32] Spécifications Algébriques de Type Abstrait des données (SATA)
[33] Modélisation d'Entreprise pour la Conception Intégrée
[34] AIde à la COnception des Systèmes de COnduite des Processus (AICOSCOP)

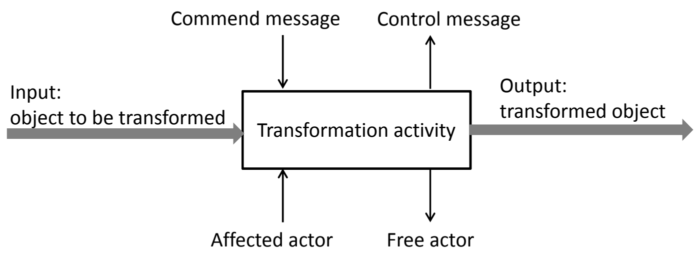


Figure 3.10: Activity viewed in MECI

To model a system following this method, a formalism is developed in four "points of view or aspects" (see fig. 3.10): functional, informational flow, decisional, and organizational [Darras 2004].

3.3.7 BPMN, a notation for process modeling

Business Process Modeling Notation (BPMN) is a standard notation to represent complex business processes. BPMN is the result of two streams of work from the late 90's - early 21st century: one on workflow management and planning and the other on modeling and architecture. One primary goal of BPMN is to be user-friendly for both business analysts and modelers and for business users [White+ 2008]. BPMN helps improve the traceability and transparency of business processes [Ferchichi 2008].

The BPMN notation is similar to that used in Unified Modeling Language (UML)[35].

In BPMN, activities, information flow, and actors are respectively represented by rectangles, arrows, and pools (lanes as the sub-partitions in a pool)[36]. BPMN is integrated in the standards of Object Management Group (OMG) [Benson 2009].

3.4 Synthesis and choice

The objective of this study is to investigate the problem of delay in collaborative decision-making in enterprises. As we have seen in this chapter, the decision-making process is decomposed into several stages which contain different activities: identifying and understanding a problem, seeking and processing information on possible options and their consequences, creating other options if needed and possible, considering new information, choosing an option and reviewing this choice [Stenzel+ 2010; Simon 1960; Janis+ 1977]. These activities trace the trajectory of information to decision and allow the decision-making process to be studied in order to understand and improve it.

As is shown in the literature [Vernadat 1996; Browning 2002; Davenport 2009; Hammer+ 1993], modeling helps represent, understand, analyze, manage, and improve complex processes. In the study of delay in collaborative decision-making, modeling the decision trajectory: 1) defines each activity specifically, including its

[35] BPMN includes the technical detail necessary to "specify messages involved in web service delivery and the generation of XML-based Business Process Execution Language (BPEL)" [Benson 2009].

[36] http://www.omg.org/bpmn/Documents

Table 3.2: Different methods of enterprise modeling, adapted from Darras 2004

Method/Point of view	Func.	Info.	Reso.	Orga.	Deci.
IDEF	YES	NO	NO	NO	NO
GRAI	NO	NO	NO	NO	YES
OLYMPIOS	YES	YES	NO	NO	NO
MECI	YES	YES	NO	YES	YES

input, output, and the actor(s) who perform it, 2) identifies the causes of delay related to each activity and also the possible improvements, 3) allows actors to "visualize where they are in a process", when they intervene, what they need, and what they have to do [Browning 2002]. In order to model decision-making processes in enterprises, we have reviewed some tools and methods, mostly proposed in enterprise engineering.

At first glance, the columns of the Zachman framework seem attractive, since they relate to the wh-questions on the decision-making process (see section 2.3 on page 37). But “the Zachman framework can lead to a documentation-heavy approach”, argues McGovern 2004 who adds that each cell of the framework needs to be informed and supported, which potentially implies a lot of documentation, “so you have to really think about what information you actually need versus what information it is nice to have...”

IDEF was not primarily designed to cover resource and organization aspects. Only IDEF12 specify these aspects. Additionally, as tab. 3.2 shows, it does not take into account decisional aspects [Darras 2004].

The GRAI grid is a practical modeling tool, giving a comprehensive, "one-page model" to explain the structure of the management system to the executives of an enterprise. It gives considerable weight to the identification of decision centers in order to manage a system. But“the GRAI grid does not aim at the detailed modeling of information processes... Other formalisms may be used for modeling the internal behaviour of decision centres, *i.e.* to describe how decisions are made; *e.g.* GRAI nets” [Doumeingts+ 2006]. However, GRAI nets are "unnecessarily complex" for this application [Browne+ 1995].

The purpose of the OLYMPIOS model is to construct the IS of a given operator, while our objective is to model the decision-making process.

Inspired by CIMOSA, MECI offers functional, informational flow, decisional, and organizational views, but derivation and instantiation are not explicitly taken into account by MECI.

The generation axis of CIMOSA covers four aspects of enterprises: functional, informational, resource, and organisational. These aspects are those that appear in our research questions, presented in section 2.3 on page 37 and also those considered as important in the scope of enterprise modeling, presented in section 3.2.2 on page 49 [Curtis+ 1992; Vernadat 1996]. Its derivation axis helps construct our model and its instantiation axis helps specify the level of our model. In sum, the advantages of CIMOSA are its modularity, its approach by views, its stepwise derivation, and its re-usability [Kosanke+ 1994]. Therefore, we have chosen the CIMOSA architecture to model the Go / No Go decision-making process in drug development projects.

We now need a notation or language to represent the elements of the CIMOSA architecture. As a notation, we have chosen BPMN to represent Go / No Go decisions, because of its several advantages [Benson 2009]:

– showing explicitly who does what, where, and in what sequence, including trigger events,
– including preceding and following messages of each activity,
– managing the level of details, using sub-processes.

In the next chapter, we present our method to provide a model of Go / No Go decisions using CIMOSA as an architecture and BPMN as a notation.

4

Modeling the decision-making process - our method

Method is much, technique is much, but inspiration is even more.
Benjamin Cardozo

Recurrent delay in decision-making reveals a dysfunction in the activities that should be performed within these processes to make decisions. Process modeling represents these activities and their links in a model. Such a model can be used as a "baseline" to improve the process that it represents [Browning 2002], through examination of its activities in terms of quality, time, and cost of their results. To investigate the indecision problem in enterprises, the process applied to decision-making should be modeled in order to be examined.

In the previous chapter (in section 3.2.3 on page 51), some modeling processes, existing in the literature, are presented and some of their strong points are pointed out. In this chapter, to model collaborative decision-making processes, we propose guidelines which contain 12 steps of the modeling methods mentioned (see fig. 4.1): 1) identify, understand, and characterize the problem to be solved by modeling [Ford 2009], 2) specify the purposes and characteristics of the chosen model [Gabor+ 2003], 3) collect prior information about the system to be modeled [Gabor+ 2003], 4) state questions to be answered [Albright 2011], 5) make hypotheses about the answers to the questions asked [Giordano+ 2008], 6) select modeling approach [Albright 2011], 7) select the structure of the model [Gabor+ 2003], 8) state assumptions [Giordano+ 2008; Albright 2011], 9) construct model and simplify if needed [Giordano+ 2008; Albright 2011], 10) answer questions and refine model if needed [Giordano+ 2008; Albright 2011], 11) plan the next step of the study using the model created, 12) validate the model and the plan of study by experts. In the following sections, each step is adapted to the problem of delay in collaborative decision-making in enterprises.

4.1 Identification and characterization of indecision problem

4.1.1 Symptoms of indecision in enterprises

Fig. 4.1 illustrates the steps of modeling as a guideline in the form of a process. The first step to make decisions more effectively and rapidly, is to diagnose potential difficulties in decision-making. The main pathology of indecision is persistent delays in decision-making, resulting from either postponement of decisions or invalidation of decisions *a posteriori*. Some causes of indecision are given in appendix A on page 173. If these causes are repeated in a visible / recognizable way, they warn of possible decisional pathology and can be considered as symptoms of indecision. All these causes / symptoms may also be revealing in the context of indecision in enterprises. However, collaborative and contextual factors related to indecision are less widely taken into account. The following, more or less strong, symptoms help identify a decision[1] pathology at collaborative level in an enterprise, at four key times:

1. **before decision meeting**: decisions are not considered as "results" for which quality, time, and cost are defined and planned. If the quality of a decision is difficult to define, the time devoted to making a decision and the cost of a decision in terms of information and expertise are quantitative values that are easier to plan. Vigilance at this stage is a preventive measure to prevent delay in decision-making,
2. **during decision meeting**:
   - lack of discussion in decision meetings,
   - endless contradictory discussions in meetings,
   - decision postponement is not explicitly assumed,
   - holding and re-holding meetings by the same people for the same decisions on the same information,
3. **after decision meeting and before decision execution**: lack of determination in the execution of a decision,
4. **after decision execution, when its consequences are known**: the ultimate symptom that confirms a problem in decision-making is frequent lack of results that depend on a decision, such as a low quality, time-consuming, or high-cost product or service, compared to what were planned.

When an indecision problem is diagnosed, the decisions delayed should be characterized in order to study the impacts of their characteristics on delays.

4.1.2 Characteristics of decisions delayed

The characterizations of the delayed decisions and also the specificities of their industrial context offer areas of research into the causes of the problem, and also reveal the improvement areas. For example, if delayed decisions concern only a particular phase of a project, the particularity of this phase should be examined to understand what held up the decisions. This characterization may be guided by the verification of the factors related to the decisions:

- **subject of decision**: what decisions are about,
- **type of decision**: individual or collaborative,
- **type of the projects**: R&D, production, marketing, etc.,
- **phases of the projects**: steps of the projects wherein decisions are frequently delayed,

[1] Our purpose is to accelerate decision-making, improving its quality and effectiveness. Thus, throughout this study, we consider the factors related to the quality of decisions.

- **degree of uncertainty**: whether the degree of uncertainty related to object, subject, and context is particularly high (see definition of uncertainty in section 2.1.4 on page 29),
- **degree of complexity**: see definition of complexity in section 3.2.1.2 on page 47,
- **reversibility of decisions**: whether decisions can be revised or are definitive,
- **emergency of situations**: depending on the time available to decide and lapse of time between decision-making and appearance of the consequences,
- **context of decision-making**: specific factors related to the context of a given enterprise, such as its sector (public, private) that may affect way decisions are reached,
- **functions of decision-makers**: functions of decision-makers in the information life cycle, meaning whether they also prepare information relating to the decision.

The specificities of the industrial field may add other characteristics to the problem. After identification and characterization of the problem (step 1, fig. 4.1), the purposes of the model should be specified.

4.2 Purposes and characteristics of the intended model

“Models are used when it is easier to work with a substitute than with the actual system... They are useful when they help us learn something new about the systems they represent” [Ford 2009]. In the case of our study, the purpose of modeling the decision-making process is to improve and accelerate the process. A model of the decision-making process is then intended to:

Purposes of model

1. include and clarify the information life cycle, including the activities to be performed, the contribution of the actors, specifying their roles *e.g.* those who generate information and those who use it to make decisions,
2. help to understand how a consensus is reached in a collaborative decision and why sometimes it is difficult to reach,
3. be used as a baseline to discuss issues with industrial actors in order to identify the activities that are frequently delayed in this process and to collect information on the way activities are performed (current practices). An understandable graphical model ensures the process is understood by the modeler and facilitates communication between modeler and industrial actors. This use of the model is the subject of part III on page 107,
4. help actors "visualize" [Browning 2002] the entire decision-making process to favor collaboration and transparency.

In addition to being inherently purposive [Gluck+ 2005], the model of the decision-making process is specified by its:

- **point of view** [Vernadat 1996]: four views of the generation axis of CIMOSA [AMICE 1993], namely the function view, information view, resource view, and organization view, *Characteristics of model*

- **scope** [Curtis+ 1992; Vernadat 1996]: initially, the scope is limited to the information life cycle. Some supplementary questions may arise which cannot be answered using the model. In this case, the model can be refined, evolving in breadth (expanding its scope), if an activity or an actor is not included or evolving in depth, if more details are needed (an activity should be detailed in several tasks / actions and a task should be detailed in several operations) [Giordano+ 2008; Albright 2011],
- **representation language, notation** [Vernadat 1998]: since the model is intended to be used as a "baseline" to discuss the decision-making process with industrial actors, an understandable graphical form is suitable to visualize this process. Diagrams, flowcharts, BPMN[2] (see section 3.4 on page 59) are some examples,
- **instantiation level** [Vernadat 1996]: generic, partial, or particular levels of the instantiation axis of CIMOSA (see section 3.3.2 on page 55) that depend on the use of model, meaning respectively a basic construct of the modeling language, a reusable model for a given sector, or a particular model of a given enterprise.

Some other characteristics such as detail level [Ross+ 1977] and degree of formalism [Vernadat 1998] can be specified progressively during the construction of the model, through simplifying and refining loops. After specifying the purposes and characteristics of the desired model (step 2, fig. 4.1), we collect information about the systems to be modeled (step 3, fig. 4.1). This information concerns the elements of the enterprise that should be taken into account in the model, such as the activities, their combinations, their inputs and outputs, the actors and their roles, etc. In industrial contexts, it might be difficult, even impossible, to observe a whole process in the case of long-lasting or distributed processes. Additionally, observation in complex sectors is not sufficient to understand the decision-making process and thus explanation by experts is necessary. Our approach is based on the descriptions of the decision-making process through a bibliographical study and especially the descriptions of actors involved in the industrial sector studied. The information collected helps to formulate the questions to be answered.

4.3 Questions and hypotheses

Based on the points of view of the generation axis of CIMOSA, questions related to the decision-making process in an enterprise or an industrial sector, can be (step 4, fig. 4.1):

- **what are the stages / activities of the decision-making process?** (function view): as described in section 3.1 on page 43, the stages of the decision-making process include the information life cycle from information research to decision-making. The model should highlight the purpose of each stage, the activities that should be performed in each stage, and the inputs and outputs of each activity,
- **what is the information flow?** (information view): the model should take into consideration the information flow through the activities of the process

[2] http://www.omg.org/bpmn/Documents

in order to track information, support transparency, and identify potential difficulty in the transfer of information,

- **who are the actors of the decision-making process?** (resource and organization views): the role of the actors in each activity should also be taken into account in the model in order to help their collaboration,
- **how activities are performed?** (practice view, added to CIMOSA): as the ISO 19439 norm states, if necessary, an additional modeling view can be added to CIMOSA. In order to study the practices implemented by the decision-makers, to assess causes of delay and to propose some improvements to reduce it, we have added the practice view to the generation axis of CIMOSA. This view corresponds to the behavioral aspects (the way activities are carried out *i.e.* practices) in the scope model proposed by Curtis+ 1992 and Vernadat 1996, presented in section 3.2.1.1 on page 46. However, similarly to CIMOSA, other tools and methods of enterprise modeling presented in section 3.3 on page 54, to the best of our knowledge, do not cover practice aspect in their formalisms. We consider this aspect in our study, but do not aim to study practices directly through modeling. In part III on page 107, an interview-based approach is adopted to answer this last question, using the model constructed in this part.

These questions guide model building and its contents. The next step is to make hypotheses about the answers to these questions (step 5, fig. 4.1). In an exploratory study, we may only ask questions. In a more advanced study, we may have some ideas to make hypotheses that can be tested.

4.4 Systemic analysis approach found on process-based model

In section 3.2.1.2 on page 47, some typologies of models are presented, such as structural, functional, behavioral models, etc. The choice of model depends on its purposes.

"An enterprise is by nature a complex dynamic system" [Vernadat 1996]. Collaborative decision-making, in such a complex environment, often implies the contribution of several multidisciplinary actors to numerous activities.

In order to investigate dysfunctions in a collaborative decision-making process that lead to problems of delay, this process should be considered in its entirety from information seeking to decision-making. The effects of the actors' interactions should be considered. Thus, a systemic approach (see tab. 3.1 on page 50) founded on a process-based model, which takes into consideration "ways of chaining activities" [Vernadat 1996] and consequently the actors' interactions, is appropriate to studying the complex problem of delay in collaborative decision-making (steps 6, 7, fig. 4.1).

4.5 Simplifying and refining loops

The next three steps, namely making assumptions, constructing the model, and answering questions are interconnected (respectively steps 8, 9, 10, fig. 4.1). The first assumption, concerning the scope of the model, is already stated in step 2. More assumptions are often needed in order to construct and formulate the model.

Table 4.1: Simplifying and refining loops in modeling, adapted from Giordano+ 2008; Albright 2011

Simplifying loop	Refining loop
1. Limit the scope of the model.	1. Expand the scope of the model.
2. Neglect some components (or variables / parameters) of the system.	2. Consider more components of the system.
3. Aggregate some components	3. Consider components in more detail.
4. Neglect changes in some components of the system (consider some variables as constant).	4. Allow changes in the behavior of components.
5. Neglect / simplify some relationships between the components of the system.	5. Consider more (complicated) relationships.
⇒ The number of assumptions increases.	⇒ The number of assumptions reduces.

The steps of CIMOSA (see section 3.3.2 on page 55) can be followed to construct the model. Then, a checklist should be applied to verify whether the model answers the questions stated in step 4. Otherwise, refining / simplifying loops should be repeated until a "manageable" model can be formulated that answer questions. Tab. 4.1 summarizes the simplifying and refining loops through changes in assumptions[3].

As explained in section 4.3, the questions about the practices implemented by the actors in performing the activities of the decision-making process is not intended to be answered through modeling. It requires the interview-based approach adopted in part III on page 107. Thus the last step of modeling is to prepare the model and to plan the study of practices (step 11, fig. 4.1). The quantitative models can be verified by testing on real data or by simulation. The qualitative models, meaning those with no quantitative results, should be verified by the experts of the industrial sector (step 12, fig. 4.1). In the next chapter, we follow these steps to model the Go / No Go decision-making process in drug development projects.

[3] See also the principle of selection in section 3.2.2 on page 49, and the four categories of assumptions in the fourth step of the modeling process proposed by Albright 2011 in section 3.2.3 on page 51.

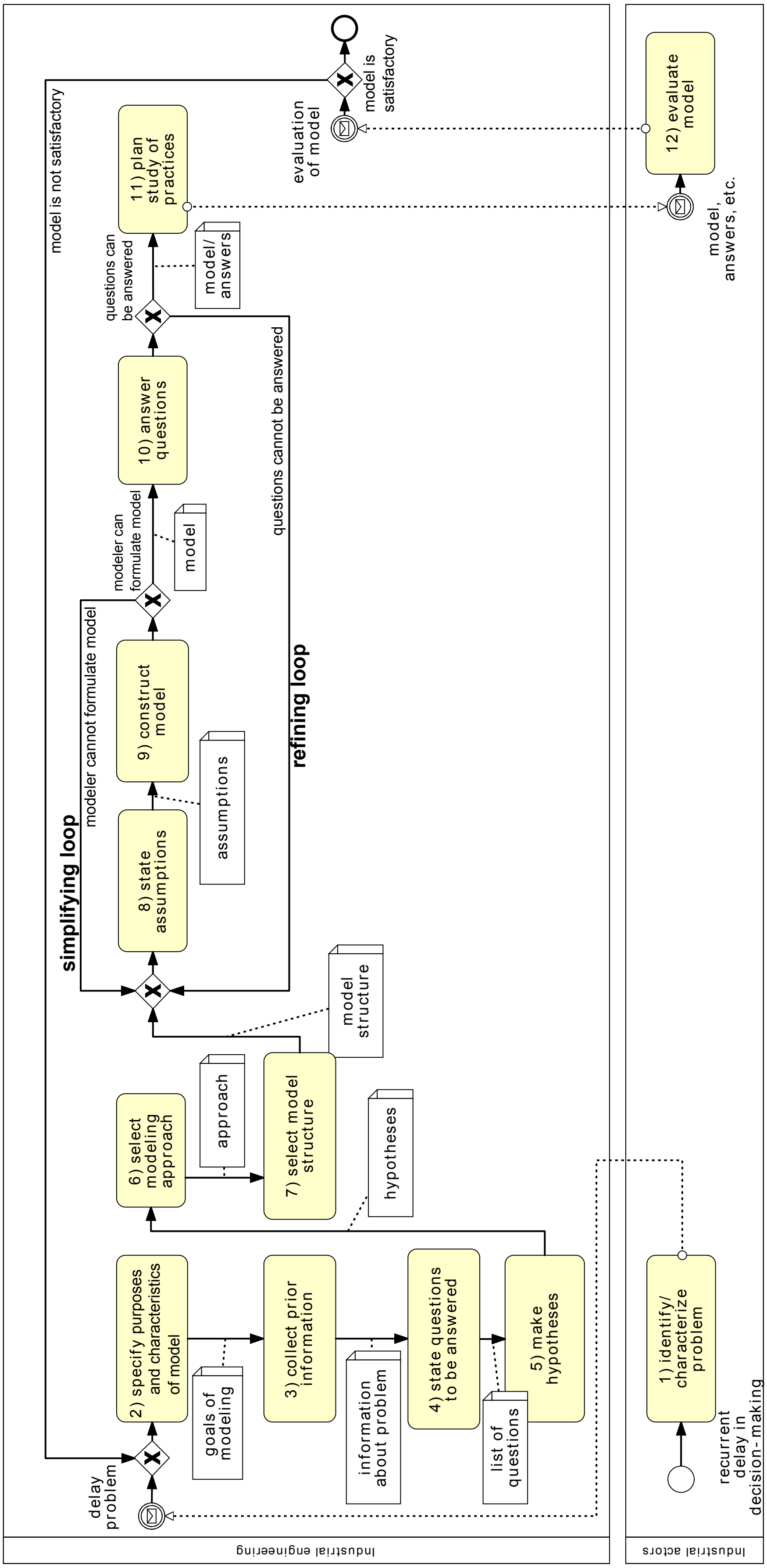


Figure 4.1: Steps of our method to model collaborative decision-making through a systemic approach, in BPMN with Signavio®, adapted from Gabor+ 2003; Giordano+ 2008; Albright 2011

5

Process modeling - application and results

The purpose of models is not to fit the data but to sharpen the questions.
Samuel Karlin

The purpose of this chapter is to construct a model of the Go / No Go decision-making process and its underlying information life cycle in drug development projects. This model helps in understanding and analyzing the decision-making process in order to reduce delays, answering and refining our questions (see section 2.3 on page 37). It also facilitates collaboration, coherency, and transparency between different actors. To construct this model, we have followed the modeling steps presented in chapter 4 on page 63.

5.1 Identification and characterization of the problem of delay in Go / No Go decisions

As explained in chapter 1 on page 9, our study focuses on difficult Go / No Go decisions. When the safety of a compound is questionable, a No Go decision is always *easy* and rapid. It is more difficult to make a Go / No Go decision when the competitiveness of a molecule is questionable, compared to the existing medicines on the market and the competing products. For the latter, little is known about the competitors' activities and their products under development, which makes the context much more uncertain. In these cases, several symptoms may alert us to a delay pathology in decision-making.

5.1.1 Symptoms of delay in difficult Go / No Go decisions

The problem, namely delay in decision-making, is underlined by our industrial partner, a specialist in pharmaceutical development with 20 years of collaborative experience with several pharmaceutical companies. It should be noted that our study is based on the various collaborative experiences of our industrial partner and also thanks to collaboration with a set of pharmaceutical R&D actors who are working or have worked in different pharmaceutical companies. Thus, the results concern the pharmaceutical industry and not a given enterprise. The symptoms which have drawn the attention of our industrial partner and his colleagues to a recurrent delay in difficult Go / No Go decision-making are as follows[1]:

1. **before decision meeting**: some decision-makers wait for more accurate information,
2. **during decision meeting**:
   – some decision-makers do not participate in debates,
   – endless contradictory discussions in meetings,
   – some meetings end without a (clear) decision, not explicitly assuming the postponement of decisions at the end of meetings,
   – holding and re-holding of meetings by the same people for the same decisions on the same information,
3. **after decision meeting and before decision execution**:
   – some decisions are made but not respected,
   – some actors try to change a decision that has already been made,
4. **after decision execution, when its consequences are known**: no new product is launched.

5.1.2 Characteristics of Go / No Go decisions delayed

In order to investigate delay in decision-making, delayed decisions should be characterized. Each characteristic may potentially cause or reduce delay in decision-making. Go / No Go decisions are characterized by the following elements (defined in section 4.1.2 on page 64):

– **subject of decision**: whether the development of a new molecule should be continued or stopped, depending on the results of the tests, which are inconclusive,
– **type of decision**: collaborative in enterprises, since Go / No Go decisions are made by a steering committee wherein individual differences and interactions between experts may complicate the decision (or indecision) process,
– **type of the projects**: drug development projects,
– **phases of the projects**[2]: five Go / No Go decision milestones mark:
   1. the beginning of the development: transition between the last phase of research, meaning Lead optimization phase to the first phase of development, namely Preclinical phase,
   2. the first tests on human beings: transition between Preclinical phase to phase I,
   3. the end of an exploratory study and the beginning of a pivotal study with statistically significant evidence of efficacy: transition between phase II-a to II-b,

[1] These symptoms are confirmed through in-depth interviews with some other industrial actors, which are presented in part III on page 107.
[2] Phases of development projects are explained in section 1.2.1 on page 14.

4. the tests on a large number of patients: transition between phase II to III which is one of the most crucial Go / No Go decisions, because it implies taking risks to human health and involves considerable time and financial investment,
5. the end of the development: transition between phase III to submission to launch.

– **degree of uncertainty**: Go / No Go decisions are taken under uncertainty, inherent in innovation, due to the lack of knowledge about the safety, efficacy, and quality of the new compounds, changes in regulation, and also the competitors' activities,
– **degree of complexity**: a large amount of interconnected information from various fields must be taken into account to make Go / No Go decisions (see section 1.2.2 on page 16),
– **reversibility of decisions**: Go / No Go decisions can be revised and remade,
– **emergency of situations**: non-emergency due to long duration of the projects, since pharmaceutical R&D projects take more than ten years, thus decisions may not seem urgent, compared to emergency situations such as accidents, crises, or disaster contexts wherein an immediate decision and reaction is necessary. The consequences of Go / No Go decisions are not immediate, so some delays may be ignored or tolerated,
– **context of decision-making**:
  – **internal context**: some elements specify the context in a given enterprise: enterprise size (start up, medium, large), type of governance (family, private or public) specifying percentage quoted on the stock market, pipeline flow (and its stability), etc.,
  – **external context**: the pharmaceutical industry has an environment with a lot of uncontrollable factors such as regulatory changes, market dynamics, competitors' activities, stakeholders' expectations, practitioners' conviction about a new drug,
– **functions of decision-makers**: chemists and pharmacologists, pre-clinical experts, and clinicians are the major R&D actors of the steering committee in charge of making Go / No Go decisions, where most of these experts do not possess the multidisciplinary knowledge to decide.

5.2 Purposes and characteristics of the model intended for Go / No Go decision-making

The purposes and characteristics of the model of the Go / No Go decision-making process are those presented in section 4.2 on page 65. Clarification is needed regarding the instantiation level: is it a generic, partial, or particular level? [Vernadat 1996] (see the instantiation axis of CIMOSA in section 3.3.2 on page 55). The model intended is neither a basic construct of the modeling language, *i.e.* a generic model, nor a model for a given enterprise *i.e.* a particular model. It is a partial model for a given sector, namely the pharmaceutical industry. The intended model is based on the description of the Go / No Go decision-making process in the pharmaceutical center, by the actors who have been worked in several enterprises and propose a partial model for these decisions. Since public health is at stake in drug development projects, different phases of these projects are strictly defined by regulatory authorities. This makes it possible to create a model that can be used as a "basic" to drive "particular models" for enterprises (see Vernadat 1996).

The questions are those introduced in section 4.3 on page 66, and the approach adopted is a systemic approach explained in section 4.4 on page 67.

5.3 A model for Go / No Go decision-making, first level of detail in a pyramidal form

The Go / No Go decision-making process, including its underlying information life cycle, is modeled at three levels which are the results of three major refinements: 1) at the first level, the Go / No Go decision-making process is presented in 4 macro stages (from understanding the problem to decision-making), 2) at the second level, each stage is detailed in terms of the activities to be performed, 3) at the third level, the last macro stage (decision-making itself) is detailed in terms of cognitives processes involving in information processing at individual level and consensus shaping at collaborative level.

5.3.1 Description of the model in a macro vision - first level

Fig. 5.1 illustrates the model of the Go / No Go decision-making process, at its first level of detail, in a pyramidal form. The main views expressed in the generation axis of CIMOSA are the basis on which to collect information and model the Go / No Go decision-making process:

1. organization view (context), *i.e.* the position of the actors in a pyramid form: at the top of the pyramid, we see the steering committee in charge of decision-making. In the middle of the pyramid, we can see the project manager who pilots the project in collaboration with experts and some experienced functional managers who together form the core team, and at the bottom of the pyramid the technicians who perform tests and studies,
2. resource view (subject), *i.e.* the actors: the members of the steering committee, project manager, experts, functional managers, and technicians,
3. function view (object), *i.e.* activities in italic font: activities of the information life cycle, including determining information required to make decision, generating and collecting information, interpreting and contextualizing it in order to be used in decision-making,
4. information view (object), *i.e.* the flow of information by perpendicular arrows: on the left side of the pyramid, information goes down, from the steering committee to technicians. On the right side of the pyramid, the raw data is transformed to information and goes up to the steering committee.

Four large arrows which surround the pyramid correspond to four macro stages of decision-making, based on the decision-making processes proposed by Simon 1960 and Janis+ 1977 (see section 3.1 on page 43): 1) Intelligence and Design stage, 2) Test stage, 3) New Information Analysis stage, and 4) Choice and Review stage. The stages

1 and 4 take root in the simple and clear decision-making process proposed by Simon 1960 which corresponds to the first and last stages of the Go / No Go decision-making process (see below descriptions). But Simon 1960 does not taken into account seeking and analyzing new information and updating previous knowledge as a stage, which is the case in the process proposed by Janis+ 1977 and also in drug development projects (through new tests and studies). Thus, the explanation of the second and third stages of the Go / No Go decision-making process are based on the process of Janis+ 1977.

The **first stage**, Intelligence and Design, on the left side of the pyramid (see fig. 5.1), corresponds to the first two stages of the Simon model (see fig. 3.2 on page 45):

- Intelligence stage: observing reality, identifying the problem, collecting and understanding information,
- Design stage: identification of the criteria and construction of the alternatives.

In the case of drug development projects, the process of Go / No Go decision is triggered when the research department obtains some *a priori* "good" results on a new compound and the steering committee must decide whether research and development of this compound should be continued or stopped.

The steering committee observes the primary results on the molecule, its therapeutic axis, etc. The committee defines the project goals and establishes a list of questions about the properties of the molecule, its activity and behavior in the human body, etc. The steering committee transmits the list of the project goals and related questions to the project manager who, in collaboration with the core team, should collect information to answer questions, identify the criteria that can help, first, design the development plan, then construct the alternative, and finally, make a Go / No Go decision. The core team is formed by the project manager, some internal and external experts, who have various levels of expertise in dealing with different aspects of drug development, and finally some functional managers, depending on their expertise and experience.

The project core team is in charge of defining the Target Product Profile (TPP) as a key strategic tool guiding drug development. TPP is the key design template for creating the development plan and should be defined by the project team, as it is a multidisciplinary activity [Kennedy 1998].

Focusing on the TPP, and in accordance with the Notice To Applicants (NTA)[3], the project team determines the development plan, including the list of tests and operational conditions.

Both TPP and development plan should be validated by (some members of) the steering committee or the R&D director, before transmission to the technicians who perform the tests.

The **second stage**, test, at the bottom of the pyramid (see fig. 5.1), corresponds to the fourth stage of the process proposed by Janis+ 1977: searching for new information relevant to the choice. In the Test stage, the technicians carry out the tests and transmit the raw data to the functional managers.

[3]NTA produces a series of regulatory guidance norms for development of medicinal products. "NTA was drawn up by the European Commission in consultation with the competent authorities of the Member States, the European Medicines Agency and interested parties in order to fulfil the Commission's obligations" [EC 2008].

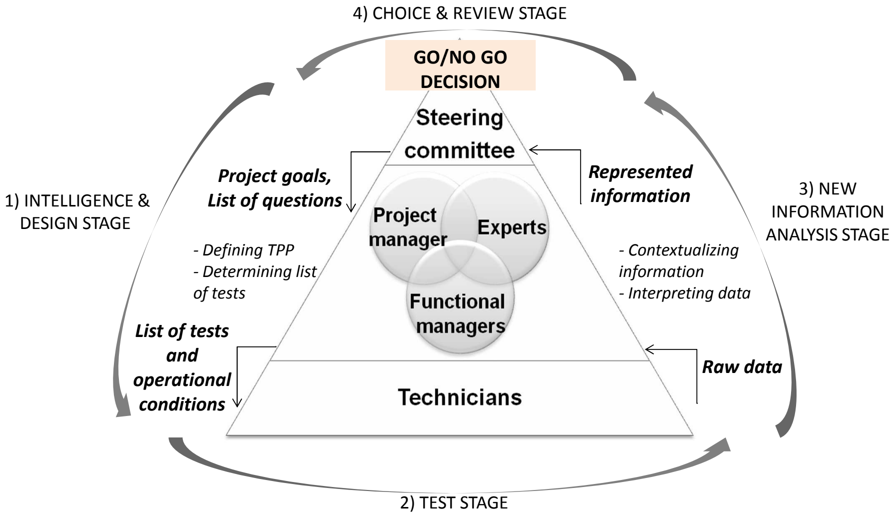


Figure 5.1: Four macro stages of Go / No Go decision-making process

The **third stage**, new information analysis, at the right side of the pyramid (see fig. 5.1), corresponds to the fifth and sixth stages of the process proposed by Janis+ 1977:

- "assimilating and taking account of any new information or expert judgment, even when the information does not support the initial choice of course of action,
- re-examining the positive and negative consequences of all known alternatives, including those originally regarded as unacceptable, prior to making a choice."

In this perspective, the raw data will be interpreted by functional managers. Project managers and experts contextualize the information depending on the project goals and consult functional managers to carry out the new tests, if necessary. Finally, the contextualized results of the tests and also the recommendations of the project manager are presented to the steering committee.

The **last stage**, Choice and Review, at the top of the pyramid (see fig. 5.1), corresponds to Simon's model: "weighing the consequences of actions, gaining confidence in the decision, and planning the action" (see fig. 3.2 on page 45). During this stage, the steering committee uses a benefit-risk analysis to decide whether to continue or not. During the Choice and Review stage, based on the presented results and the recommendations of the project manager, the steering committee makes a Go / No Go decision, if the results are conclusive and allow the benefit-risk balance of the new compound to be assessed. If the results are not conclusive enough due, for example, to incomplete or contrary results, the steering committee may ask for some additional trials and studies and the process is iterated. Information becomes progressively accurate and complete and decision-makers should take into account the results of the new tests to make a decision or revise a decision made[4].

[4]We have proposed a decision support system to take new information progressively into account in decision-making when faced with uncertainty and give an illustrative example in (see Hassanzadeh+ 2011c)

Table 5.1: Example of the simplified results of stability measurement tests

Time/Temperature	0°	5°	25°
t_0	13,0000 $\mu g/l$	13,0000 $\mu g/l$	13,0000 $\mu g/l$
t_{1month}	12,9999 $\mu g/l$	12,9999 $\mu g/l$	12,9995 $\mu g/l$
t_{6month}	12,9998 $\mu g/l$	12,9997 $\mu g/l$	12,9980 $\mu g/l$
$t_{12month}$	12,9997 $\mu g/l$	12,9995 $\mu g/l$	12,9935 $\mu g/l$
$t_{1month} + H_2O$	—	12,9994 $\mu g/l$	12,9945 $\mu g/l$
$t_{6month} + H_2O$	—	12,9993 $\mu g/l$	12,9942 $\mu g/l$
$t_{12month} + H_2O$	—	12,9991 $\mu g/l$	12,9934 $\mu g/l$

5.3.2 Illustration of the model - first level

This process is illustrated by an example of one of the criteria on which Go / No Go decisions is based. The purpose of this example is to highlight which type of information the Go / No Go decisions are based on, how this information is concretely produced in the form of initial raw data, and which elements are taken into account to interpret this raw data.

Many questions need to be answered to prove the safety, efficacy, and quality of a molecule in order to make a Go / No Go decision. The toxicity of the molecule, its stability, clinical and side effects, mechanism of absorption and distribution in / elimination from the human body, are a few examples of these questions.

The stability question is a part of the quality question: is the product stable under conditions of use? Many environmental factors affect the stability of a product. Depending on the project goals and also the available quantity of the product, the project team establishes a list of tests to be conducted in order to obtain data on product degradation in different climatic zones. Operational conditions such as temperature, humidity, and light are also determined, so that the real packaging and storage conditions are simulated. A protocol that includes this information and also the number of tests, quantity of the product, time intervals, measurement, and analysis methods have to be followed by technicians.

Tab. 5.1 presents a simplified example of the stability results. The purpose is to highlight how the raw data of this table about the degradation rate[5] of a new compound is interpreted and contextualized by the project manager and the experts. Each cell of the table shows the concentration of the compound at a given temperature (0°, 5°, or 25° - in dry and humid environments) and after a lapse of time from the beginning of the study (1, 6, or 12 months). In this way, the degradation rate of 13 $\mu g/l$ of a new compound is measured during one year, in three different temperatures and in dry and humid environments.

At time $t_0 + 12$ months, meaning after one year, technicians register – 0,05% of degradation at ambient temperature. The functional manager's interpretation is that the molecule is approximately stable. The project team, in collaboration with functional managers, contextualizes this interpretation in terms of project goals and

[5] "Progressive decomposition of a chemical compound into a less complex compound, as by splitting off one or more groups of atoms", source: `http://medical-dictionary.thefreedictionary.com/degradations`

tries to answer the following questions. Does this degradation rate affect the efficacy of the molecule in usage conditions? Could the degradation rate be reduced in another container such as a blister? In relation to the results of other studies, such as toxicity, is this degradation rate acceptable? The answers to these questions are often tainted with a degree of uncertainty.

5.3.3 Questions answered in / arising from the pyramidal model

The first level of our model (see fig. 5.1) highlights the global structure of the resource organization, the role of each actor in the information life cycle through the four macro stages of the decision-making process, and the flow of information from the top to the bottom of the pyramid and *vice versa*. Additionally, this representation of the information trajectory, within the decision-making process, makes it possible to analyze the role of the three classes of uncertainty factors, presented in section 2.1 on page 21, in this process, namely factors relating to object, subject, and context.

During the first two stages (Intelligence and Design stage, and Test stage), the factors related to the object (molecule) play an important role in creating uncertainty by incompleteness or contradiction of information, since the properties and the behavior of the molecule, and consequently its benefit-risk balance, are mostly unknown. Thus, the definition of the tests and protocols is relatively[6] objective, factual, and rational. Therefore, the impact of the subjective and contextual factors is limited compared to the next stages.

During the third stage (New Information Analysis stage), the results of the tests in various fields (the raw data) are progressively available and should first be interpreted. In this stage, factors related to subjects, especially individual factors, such as perception, reasoning mode, and the experience of each expert are also important. During the contextualization of information, factors related to the context are taken into account: internal factors, such as the condition of other projects in the pipeline and external factors such as market dynamics. During the representation of information, the role of subjects in the communication of results is crucial.

Finally, during the last stage (Choice and Review stage), meaning Go / No Go decision, factors related to subjects, especially collaborative factors, such as debates and different ideas about the doubtful results contribute to creating uncertainty.

The pyramid illustrates how objective, subjective, and contextual layers are progressively superimposed in the Go / No Go decision-making process. This analysis is validated by the experts, as it allows them to take into consideration the importance of each class of uncertainty factor in the different stages of the process, and especially because it raises the following questions. When decisions are frequently delayed, dysfunctions in the decision-making process and information life cycle are caused by which class of uncertainty factors? In order to identify the dysfunctions and the factors involved in these dysfunctions, the activities described in the pyramid should be detailed in more elementary activities to be examined. For example, the activities that allow the TPP, or the development plan to be defined, or the results of

[6] Sometimes the results of the tests on different kinds of animals or different populations of target patients are contradictory. In these cases, supplementary tests are needed to explain the contradictions. The choice of the supplementary tests is based on the interpretation of the first results which is, by definition, more or less subjective.

the tests to be prepared, should be detailed. Additionally, the possible outcomes of the decision-making are not explained in the pyramid.

One purpose of the model is that it can be used as a baseline to discuss issues with the actors in order to point out the delayed activities, the causes of delay, and the way to improve the process (see section 4.2 on page 65). But, the pyramidal form of the Go / No Go decision-making process is not precise enough to support such a study. Therefore, a refinement of the model is necessary. The refined model is more detailed than the pyramid, while its scope is the same, meaning the information life cycle in decision-making.

In the next section, we represent the four macro stages of the process, presented in BPMN, that show more details in an understandable, graphical form.

5.4 Second level of detail, information life cycle in BPMN

5.4.1 Description of the model in a detailed vision - second level

A more detailed description of the Go / No Go decision-making process is presented in fig. 5.2, compared to the pyramid (see fig. 5.1 on page 76). This process, thanks to elements of BPMN (see section 3.3.7 on page 59), shows more exactly the inputs, outputs, and the sequence of the activities, the role of the actors, and the information flow.

In the **first stage**, Intelligence and Design, we can see that contrary to the project goals, which are directly defined by the steering committee, drawing up the TPP and the development plan involve, first, the collaboration between the project manager and the expert committee, and then the final validation by the steering committee. This representation traces the collaboration of the actors to provide the important documents: project goals, TPP, development plan, and planning.

The **second stage**, Test, is not more detailed compared to the pyramidal form.

The **third stage**, New Information Analysis, illustrates the activities performed to transform the raw data into information presented to decision-makers: interpretation, contextualization, synthesis, aggregation, and finally presentation of the results. In addition to the results, the project manager makes some recommendations about the continuation of the project. These recommendations, like the treatment of the raw data, are made in collaboration with the expert committee.

The **last stage**, Choice and Review, highlights in a formal way, thanks to the logic operators of BPMN, the four possible outputs of the activity Analyze the results and recommendations:

- Go: if the results of studies are sufficiently *good* and demonstrate the objectives of the phase, such as efficacy for animals in the preclinical phase, the decision will be to continue to the next phase (tests on humans),
- No Go: if the results are *bad* and prove toxicity or inefficacy of the molecule, the project will be stopped,

– Go + tests: if the results are not completely satisfactory and some points need to be clarified, transition to the next phase takes place. But at the same time, the steering committee (consulting the project team) requests supplementary tests and studies. The next phase of the project begins. The process iterates, defining and performing the new tests and interpreting the new results which may confirm or question the Go decision,
– No Go + tests (temporary stopping): if the results are not entirely satisfactory, supplementary tests are requested and the project is temporary stopped, awaiting the results of the new tests which clarify and complement the previous results.

The second level of the model, as is also the case for the first level of the model (fig. 5.1 on page 76), is based on the description of the industrial actors and is validated by others as a "particular" model (see section 3.3.2 on page 55) which represents the Go / No Go decision-making in a drug development project.

5.4.2 Questions answered in / arising from the BPMN presentation

The second level of the model presented in BPMN (see fig. 5.2) gives a more detailed vision of the Go / No Go decision-making process, compared to the pyramidal form (see fig. 5.1 on page 76). It highlights the collaboration between the actors through the way of linking the activities performed by different actors. This model draws attention to three levels of collaboration:

– collaboration within the core team between the actors who produce and prepare information,
– collaboration between the core team (especially the project manager) and the steering committee when the project manager presents information to the steering committee,
– collaboration within the steering committee between the decision-makers (experts in various fields, such as chemistry, pharmacology, toxicology, pre-clinical and clinical studies, etc.) who use prepared and presented information to decide.

The first and second collaboration levels are clear in the BPMN presentation, since the actors of the project team are represented in three different lanes (see section 3.3.7 on page 59): project manager, expert committee, and technicians. It is also true for the second collaboration between the project team and the steering committee, presented in different lanes. However, one question remains unanswered: is there any problem, misunderstanding, or dysfunction in the collaboration of the project team and the steering committee? The same question arises for the collaboration within the steering committee, presented in the same lane in fig. 5.2 on the next page: how do decision-makers collaborate to make a decision? They are the experts in the various fields, but how do they perceive, evaluate, and reason on the results presented by the project manager?

In the second level of the model the Choice stage of the model is not sufficiently elaborated. The collaboration, between decision-makers within the steering committee is not at all clear. The Choice stage remains a black box[7] in this model.

[7] See fig. 3.4 on page 48.

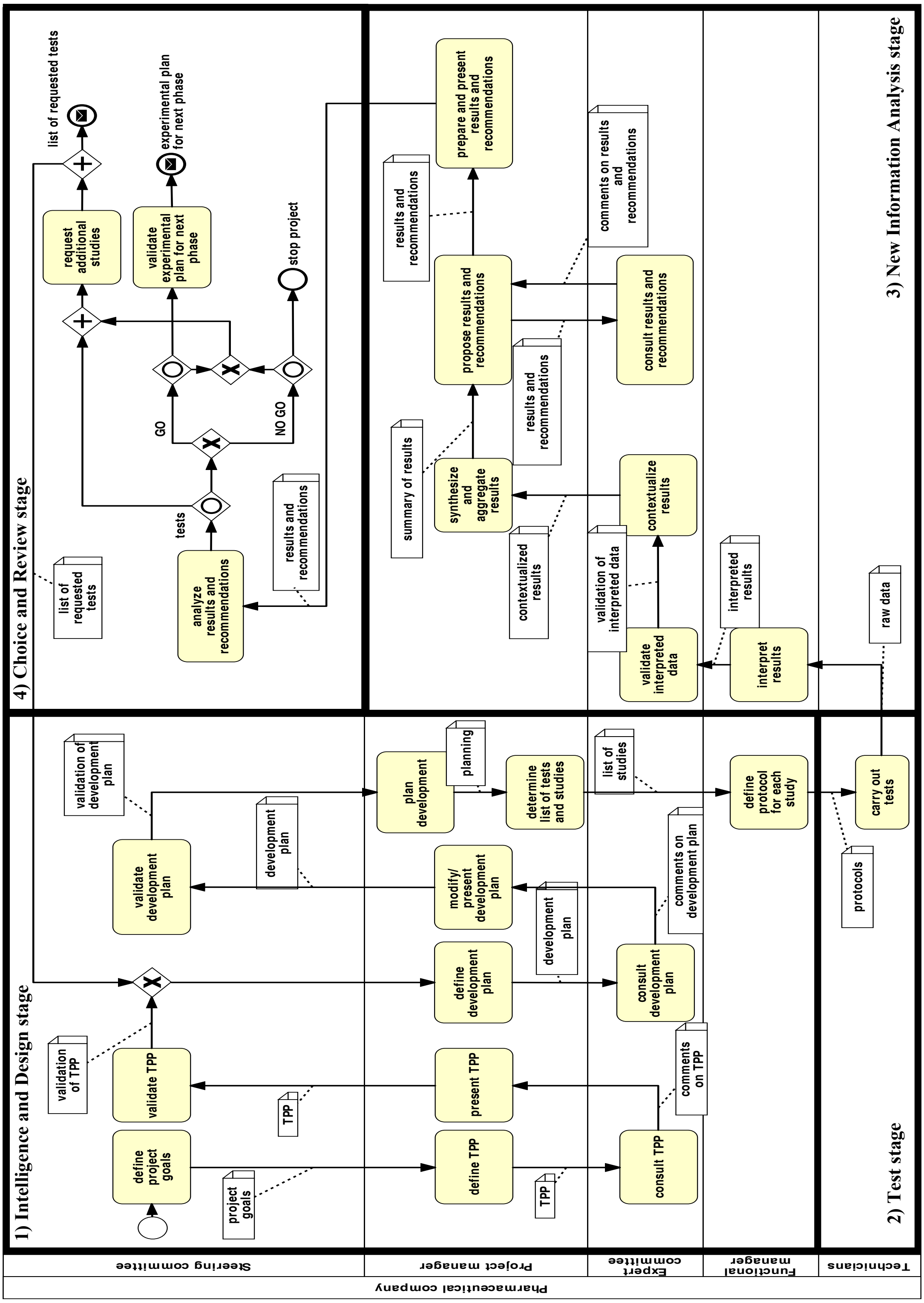


Figure 5.2: A model for Go / No Go decision-making process in drug development projects, including information life cycle, in BPMN with Signavio®

Furthermore, activities to transform information to decision are specified, but data, information, and knowledge transformation by cognitive processes throughout the decision-making process is not outlined. Thus, the refinement of the model at the last stage of the decision-making process is necessary to find out how the members of the steering committee, as the unique (group of) actors in this stage, reach a consensus to make a decision, and when and why such a decision is delayed or invalidated.

In the next section, a framework is proposed to understand the Choice stage in the case of collaborative decision-making.

5.5 Third level of detail, a framework for the collaborative Choice stage

All decision is a matter of compromise.
Herbert Alexander Simon

"All decision is a matter of compromise. The alternative that is finally selected never permits a complete or perfect achievement of objectives, but is merely the best solution that is available under the circumstances" [Simon 1947]. In the case of collaborative decisions, this compromise should be reached collaboratively. As Roy 1996 indicates, a collaborative decision-making process would usually be composed of a period of individual reflection and group interaction. A collaborative "decision will generally be the product of an interaction between this individual's preferences and those of others... The playing out of these confrontations and interactions, under the various compensating and amplifying effects of the system, makes up what we shall call the decision process" [Roy 1996].

As the pharmaceutical R&D actors describe, before the Choice stage, the project manager sends the results of the tests and studies to the members of the steering committee. Then, the Choice and Review stage begins through a meeting. This means that the Go / No Go decisions are "face-to-face", *i.e.* "several decision-makers are implicated in the decisional process and meet together around a table. This is a very frequent situation" (see tab. 5.2 [Zaraté+ 2004]).

Go / No Go decision meetings consist of two steps: 1) presenting the results of the studies by the project manager to the steering committee, 2) decision-making by the steering committee.

In this section, we detail the Choice stage of the Go / No Go decision-making process (see section 5.3.1 on page 74 and section 5.4 on page 79), in order to understand, describe, visualize, and analyze how:

- each decision-maker individually processes information, before the meeting and at the beginning of the meeting when the project manager presents the results,
- after the presentation of the results, a consensus is reached within the steering committee.

To achieve this objective, first, we present some models of collaborative decision-making in the literature. Then, our description of the Choice stage is presented which helps to define an index to measure the risk of invalidating a decision. Finally, an example illustrates the model.

Table 5.2: Collaborative decision-making situations [Zaraté+ 2004]

	Synchronous	Asynchronous
Same place	Face-to-face decision-making	Asynchronous decision-making
Different places	Distributed synchronous decision-making	Distributed asynchronous decision-making

5.5.1 Collaborative choice in the literature

Collaborative decision-making involves a group of individuals who focus on the same situation to make a decision [Maier 1967]. Freeman 1999 and Harris 2005 point out some advantages and disadvantages of collaborative decision-making:

- **advantages**:
  1. a more complete knowledge base may be available thanks to professional knowledge and experiences of individuals,
  2. more alternatives and opportunities may be considered from different perspectives, thanks to diversity of views,
  3. ownership of decision by the people who participate in decision-making and have understood the process by which decision is achieved,
  4. more legitimacy of decision,
- **disadvantages**:
  1. time-consuming process which may limit the ability to respond quickly,
  2. social pressure to conform and to avoid conflict which can squash disagreement, differences, and favor conformity[8],
  3. possible decrease of effectiveness because of the domination of the group by one person or a few individuals perceived as more powerful or more intelligent,
  4. ambiguity of the responsibility.

The first two advantages, *i.e.* more complete knowledge, experience, views, and alternatives in a collaborative decision-making process have ambivalent effects on it. On the one hand, the decision made can be well-informed and on the other hand, often more time is needed to discuss issues and reach a consensus. We focus on these two ambivalent advantages to understand collaborative information processing based on various knowledge, experiences, and views.

In section 3.1 on page 43, some decision-making processes suggested by Boyed [Stenzel+ 2010], Simon 1960, and Janis+ 1977 are presented. As explained in that section, these processes give a structure to decision and highlight the macro stages of decision-making which allow structuring of the Go / No Go decisions, taking into account the activities, such as understanding the problem, searching for information, creating options, evaluating alternatives, determining actions (see section 5.3.1 on page 74 and section 5.4 on page 79). But the Choice stage, though it might be the

[8]Conformity is related to groupthink defined by Janis 1972 as “a mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when the members’ strivings for unanimity override their motivation to realistically appraise alternative courses of action.” To read about other bias in decision-making see Hassanzadeh+ 2012b.

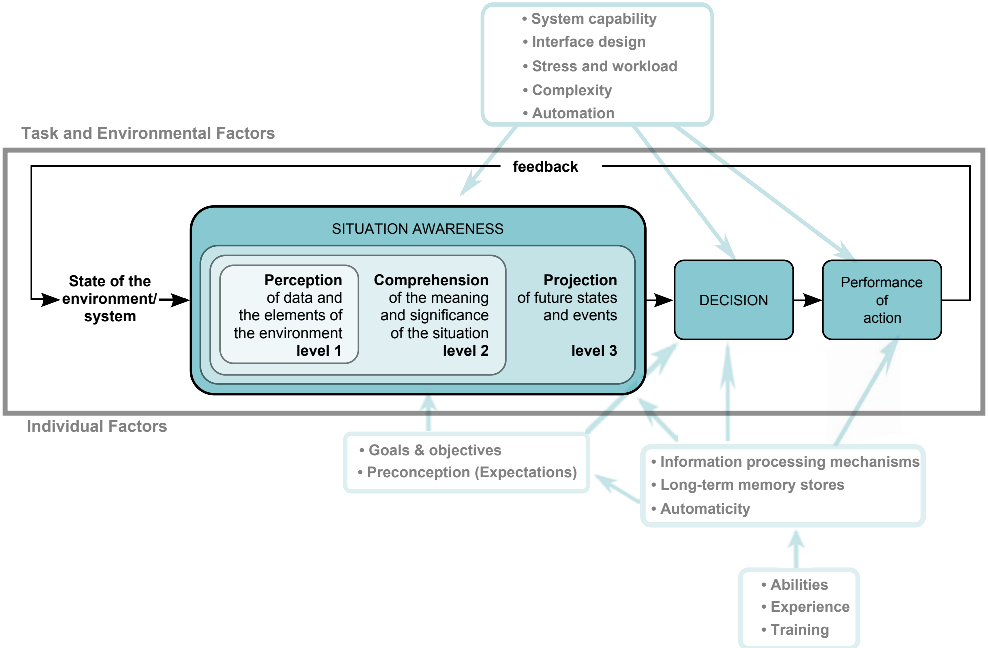


Figure 5.3: Model of SA in dynamic decision-making [Endsley 1995]

most intellectually difficult part of the decision-making process [Forman+ 2001], is not sufficiently developed in these models. For example, Pomerol+ 2008 state that Simon's model "makes it possible to connect decision and information, even though it is not rich enough in terms of understanding choice and analyzing the role of future events." Additionally, the factors that affect decision-making, such as experiences and views, are not taken into account. Another shortcoming of these processes is that even if the stages are separated, which allows the contribution of the actors in each stage to be studied, the collaboration of the actors who perform the same stage cannot be examined.

In this section, we present some models of decision-making processes that help to understand the Choice stage. Fig. 5.3 shows the model of Situation Awareness (SA) in dynamic human decision-making, suggested by Endsley 1995 who defines SA as follows: "situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Endsley 1995 distinguishes SA, as a "state of knowledge", from the "process" applied to achieve this state which consists in three hierarchical phases: perception of the elements in the environment, comprehension of the current situation, and projection of the future. SA does not simply include "perceiving information" about a situation. It also includes "comprehending the meaning of that information", and "providing projected future states of the environment". Projection of the future is achieved through knowledge acquired in both first

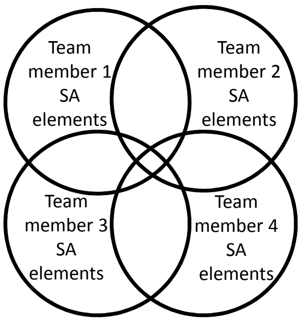


Figure 5.4: Team SA [Endsley 1995]

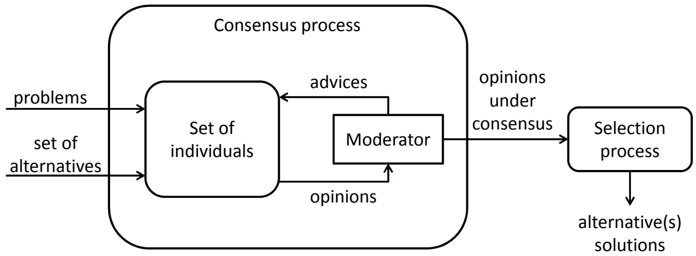


Figure 5.5: Consensus process within collaborative decision-making process [Mata+ 2009]

two levels (see fig. 5.3). In this way, a decision-maker puts together information, using various patterns to determine an action, thanks to knowledge acquired and previous experiences, avoiding possible undesirable consequences in the future, adapted to a situation[9]. SA is followed by decision-making and performance of action. Fig. 5.3 also shows several major factors which influence this process [Endsley 1995]:

– individual factors: abilities, experience, training, long-term memory stores, automaticity which affect information processing mechanisms and consequently the way to process goals,
– "features of the task environment": workload, stress, and complexity.

Fig. 5.4 shows the overlap between team members' SA, in the case of collaborative decision-making. This overlap is the subset of information which constitutes team coordination *via*, for example, a verbal exchange. Endsley 1995 considers that "the quality of team members' SA of shared elements (as a state of knowledge) may serve as an index of team coordination".

The SA model highlights the cognitive processes[10], implemented to achieve an awareness state which is necessary to make a decision. It also takes into account both individual, and "task and environment factors" that affect the decision-making process. This model is widely used in different fields[11], to improve the knowledge management process in collaborative decision. However, the team SA details neither the differences and similarities of the perception and reasoning of different members, nor their interactions (see fig. 5.4). Thus, we cannot use it to describe how a collaborative decision is formed.

A key concept that allows a collaborative decision to be made is consensus, more precisely a state of agreement between decision-makers within a group where all opinions have been addressed [Saint+ 1994]. The process that allows a consensus to be reached consists in "discussion rounds where the experts provide and change their opinions" [Mata+ 2009]. Fig. 5.5 shows a collaborative decision-making

[9] For example, "an air traffic controller needs to put together information on various traffic patterns to determine which runways will be free and where there is a potential for collisions" [Endsley 1995].

[10] "A cognitive process is one that: 1) is required for the accomplishing of a cognitive task, 2) involves information processing, and 3) is of the sort that is capable of yielding a cognitive state" [Rowlands 2006].

[11] Endsley 1995, is cited 2602 times according to Google Scholar and cited 742 times according to Web of Knowledge.

process, including the consensus process. In this model, the exchange aspect of decision-making is illustrated, but the "set of individuals" is presented as a black box (see fig. 3.4 on page 48) and we lose the SA and its influential factors on each decision-maker(see fig. 5.3). We aim to detail the collaborative Choice stage, considering both individual information processing and collaborative exchanges. Endsley 1995 provides the cognitive processes used in information processing but the nature of the objects manipulated by these processes are not explained. In the next section, we explain the distinctions and relationships between data, information, and knowledge as the objects of cognitive processes. This helps us elaborate our model of the collaborative choice, taking into account the objects which are treated differently through the cognitive processes of different actors.

5.5.2 Distinctions and relationships between data, information, and knowledge

Fig. 5.6 shows the distinctions and relationships between data, information, and knowledge and helps describe perception and comprehension levels of the SA model (see fig. 5.3).

Data

Data are the uninterpreted signals detected by senses, such as strings of numbers, characters, or other symbols, a color, etc.

Information

Information is data equipped with a meaning obtained through an interpretation. For example, a red traffic light is interpreted by a car driver as an indication to stop, while an alien whose shuttle has landed "near the Paris périphérique during the Friday evening rush hour" does probably not give the same meaning to a red light[12]. "The data are the same, but the information is not" [Schreiber 2000]. This example draws attention to the perception of the subject who receives data from an object and transforms it to information which might be different from the information produced from the same data by another subject. This subjectivity is tightly linked to that in the face of uncertainty, since uncertainty is interconnected to information[13]. Thus, as different information can be produced from the same data by different subjects, the degree of uncertainty may be different for these subjects, depending on their previous knowledge, experiences, and memory [14].

Knowledge

Knowledge is the whole data and information used to carry out actions, with two important distinct aspects: 1) "a sense of purpose", because knowledge is considered as the "intellectual machinery", and 2) "a generator capability", since one major function of knowledge is to produce new information [Schreiber 2000].

The distinctions and relationships of data, information, and knowledge are useful in understanding the mental mechanisms of the decision-makers, and to study the factors that contribute to this transformation process and consequently to the decision-making process.

[12] Another example is the acronyms and abbreviations, widely used and constantly changed in France, for an Iranian who may perceive most of them only as a chain of characters. In these situations, the context may help interpret data.

[13] "The concept of uncertainty and information studied in this book are tightly interconnected. Uncertainty is viewed as a manifestation of some information deficiency, while information is viewed as the capacity to reduce uncertainty" [Klir 2005]. See section 2.1.3 on page 27.

[14] This shows that our definition of uncertainty, presented in section 2.1.4 on page 29, appropriately takes into consideration the role of the subject in the characterization of uncertainty.

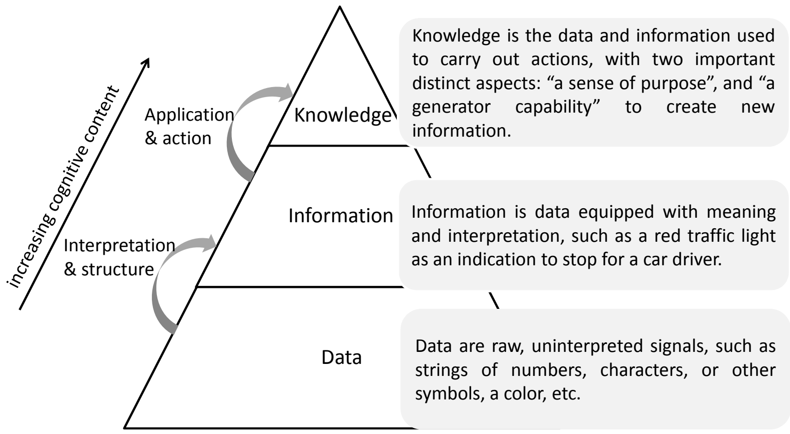


Figure 5.6: Distinctions and relationships between data, information, and knowledge [based on Schreiber 2000; Qiu+ 2006]

In complex multidisciplinary drug development projects, project managers (in collaboration with experts) interpret and contextualize the raw data and present the interpreted data to decision-makers who may:

– more or less share this interpretation,
– have another interpretation of the same data,
– not understand some pieces of information in detail, because it is not in the scope of their expertise.

To understand how each individual transforms data into knowledge and how individuals interact within a group, we have refined the collaborative Choice stage of our model (see section 5.3.1 on page 74, section 5.4 on page 79, and section 4.5 on page 67) in a framework (see fig. 5.7). In the next sections, first, the global structure of the refined model is presented, and then more descriptions are given in detail.

5.5.3 Global structure and assumptions in ISA and CSA

Information goes in, decisions come out and who knows what happens in between?
Davenport 2009

The purpose of refining the collaborative Choice stage of the Go / No Go decision-making model (see section 5.4 on page 79) is to highlight, as Roy 1996 distinguishes, "individual reflection" and "group interaction" in this stage. The models of collaborative decision-making, presented in section 5.5.1, either explain clearly the individual reflection [Endsley 1995] or visualize the collaborative aspect [Mata+ 2009]. The framework for the collaborative Choice stage that we propose takes into consideration both individual and collaborative aspects through two SA processes (see fig. 5.7). The first one, Individual Situation Awareness (ISA) corresponds to "individual reflection" pointed out by Roy 1996 and illustrates how an individual processes information. The second one, Collaborative Situation Awareness (CSA) corresponds to "group interaction" pointed out by Roy 1996 and illustrates the

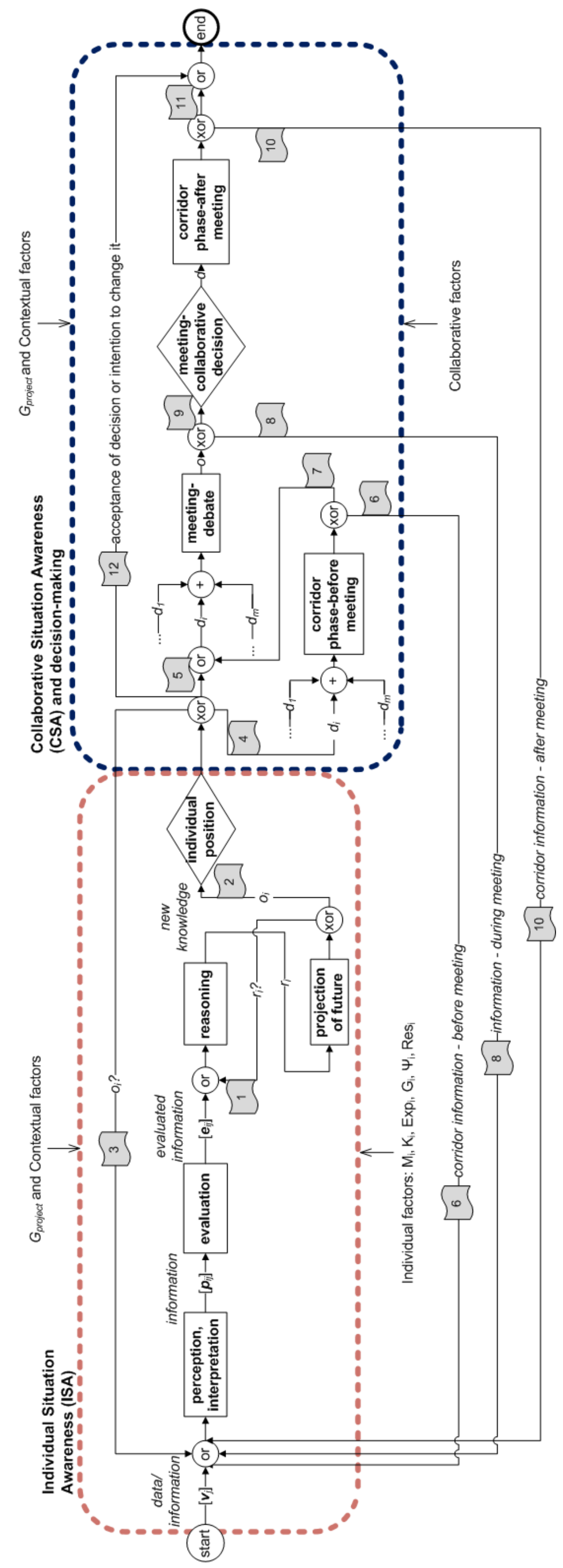


Figure 5.7: Framework for collaborative Choice stage

interactions between decision-makers that may motivate decision-makers to review and change their positions.

The model is described independently of its application field - drug development projects - and is illustrated by a pharmaceutical application.

Before detailed explanation of each cognitive process used to process information in our ISA, we underline the organizations of these cognitive processes compared to Endsley's SA model.

As Endsley 1995 indicates, his SA model (see fig. 5.3) and its underlying cognitives processes such as perception and comprehension are commonly applicable in a wide variety of areas. Inspired by Endsley's SA model, the ISA that we propose includes the cognitive processes implemented by each individual to acquire the state of awareness in the collaborative Choice stage (see section 5.5.1). This model is enriched and verified thanks to multiple discussions with our industrial partner and his colleagues.

Endsley 1995 indicates "the first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment... SA, therefore, is based on far more than simply perceiving information about the environment. It includes comprehending the meaning of that information in an integrated form, comparing it with operator goals, and providing projected future states of the environment that are valuable for decision-making." In his SA model, Endsley 1995 assigns two different boxes (rectangles) to perception and comprehension and the last one to projection of future (see fig. 5.3). In the ISA that we propose, perception is not a simple reception of data and thus, is equivalent of the first two levels of the SA model proposed by Endsley 1995: "perceiving information", including "comprehending the meaning of that information".

The next cognitive process in our ISA is evaluation of the quantitative or qualitative value of each variable perceived. In this phase, each variable is evaluated separately from the others. For example, for buying a new car some variables may be considered such as power, speed, color, fuel, etc. and the value of each of them is evaluated considering a criterion. After the evaluation of each variable, a reasoning is applied to measure how the set of values globally satisfy the goals of a decision or project. These last two steps, namely evaluation and reasoning, are not included in the SA model of Endsley 1995 (see fig. 5.3). The projection of future step is that proposed by Endsley 1995. Individual position is the equivalent of the decision box in the SA model of Endsley 1995. We do not call it decision, since in the case of collaborative decisions it is at the end of the collaborative phase that a decision is made. The collaborative phase is not included in the SA model of Endsley 1995.

In fig. 5.7, the rectangles represent the cognitive processes and the lozenges represent taking a position in the ISA and making decisions in the CSA. The circles are the logical connectors *i.e.* AND (noted +), OR, and XOR. The punched tape forms contain numbers which are used to explain the conditions related to each possibility after a XOR operator. Traditionally in the flowcharts, as we have seen in section 3.3 on page 54, the arrows pointing down and up respectively symbolize constraints and resources. The framework of the collaborative choice is not to model the operational activities, but the cognitive processes. Thus as is the case in the SA model of Endsley 1995 (see fig. 5.3), in our model (fig. 5.7) the arrows pointing down correspond to "task and environmental factors", specifying two sets: project goals noted $G_{project}$, and contextual factors as explained in our definition of uncertainty (see section 2.1.4 on page 29). Again, as with the SA model of Endsley 1995, the arrows pointing up correspond to individual and collaborative influential factors, respectively in the ISA and the CSA.

Suppose a group of m decision-makers have to make a collaborative decision d, that is shaped by individual decisions DM_i, where $1 \leq i \leq m$. The input of the collaborative decision is a vector of variables $[\boldsymbol{v}_j]$, where $1 \leq j \leq n$, and n is the number of the variables that are judged, by the group in the Design stage[15], to have an impact on a decision (a Go / No Go decision for example), satisfying a set of already determined criteria. Each decision-maker receives the same values for the n variables and processes them through four personal cognitive processes: perception, evaluation, reasoning, and projection of future, before coming to his individual position d_i and then to the collaborative decision d. The model's assumptions are defined as follows.

In order to make the model "manageable" (see the description of Albright 2011 in section 3.2.3 on page 51), we state some assumptions in the framework of the collaborative Choice stage:

Assumptions for ISA and CSA

1. all decision-makers are supposed to have, in/directly, some potential influence on Go / No Go decisions,
2. the sequence (not the results) of cognitive processes are supposed[16] to be the same for all the decision-makers: perception, evaluation, reasoning, projection of future,
3. the individual influential factors (not their degrees) are supposed to be the same for all the decision-makers, in the ISA: memory, knowledge, experiences, goals, psychological properties, and responsibilities of the decision-maker number i which are respectively represented by M_i, K_i, Exp_i, Ψ_i, and Res_i,
4. the collaborative influential factors (not their degrees) are supposed to be the same for all the decision-makers, in the CSA,
5. all decision-makers receive the same data and information. Though this model is presented independently of its application field of drug development projects, its purpose is to examine the Go / No Go decision-making process wherein the project manager sends the results of the tests to all the decision-makers who also attend decision meetings wherein the results of the studies are presented to them by the project manager.

The individual influential factors are defined as follows:

1. M_i: memory of decision-maker i helping him remember his knowledge, experiences, and responsibilities regarding a situation of decision-making,
2. K_i: knowledge of decision-maker i of the variables included in his expertise about which he is capable of reasoning and creating new knowledge,

[15] In a general vision, independent of our application field, the Design stage is refereed to the decision-making process proposed by Simon 1960, presented in section 3.1 on page 43. This stage is adapted to our application field, described in section 5.4 on page 79.

[16] Perception (interpretation, comprehension), and projection of future take root in the SA model of Endsley 1995 (see fig. 5.3). Evaluation and reasoning are based on the descriptions of the industrial actors.

3. Exp_i: experiences of decision-maker i in similar decision-making situations,
4. Ψ_i: psychological traits of decision-maker i regarding risk and uncertainty perception and also regarding other decision-makers,
5. Res_i: responsibility of decision-maker i regarding the consequences of a decision.

5.5.4 Description of the model - third level - ISA

The (red) dotted square, on the left of the fig. 5.7, shows the cognitive processes of the ISA process: perception, evaluation, reasoning, projection of future, and individual position.

5.5.4.1 Perception

Perception:

- is triggered by sensory stimuli from the environment,
- is conducted by attention[17] and intention,
- results in comprehension, by giving meaning to the data detected *i.e.* transforming data into information (see section 5.5.2).

The M_i, K_i, Exp_i, Ψ_i, and Res_i of each decision-maker i help him perceive, filter, and select the variables that have a signification and importance to him.

The input of the perception process, noted $[\boldsymbol{v}_j]$, represents the data that is received and processed by all the decision-makers. We call $[\boldsymbol{v}_j]$ a "situation", since it comprises the values of the variables that characterize a situation wherein decision-makers should decide.

The output of this process is a vector $[\boldsymbol{p}_{ij}]$ that represents the perception of the selected variables by decision-maker i. A decision-maker might not take into consideration all the variables, either because they are not meaningful to him or because they do not concern his goals. Thus, the selected variables are not the same for all the decision-makers and the number of the variables perceived by each decision-maker in the vector $[\boldsymbol{p}_{ij}]$ may vary. This means for some j, p_j may be the empty value. The vector $[\boldsymbol{p}_{ij}]$ is the input of the next cognitive process.

5.5.4.2 Evaluation

Evaluation consists in comparing the value of each variable to the criteria that concern this variable. The evaluation process of decision-maker i is influenced by M_i, K_i, Exp_i, Ψ_i, and Res_i.

Human evaluation of both qualitative and quantitative variables is expressed by linguistic terms that are often not binary. For example, the value of the perceived variable p_j can be a number, an interval, or a modality. In all these cases, p_j is qualified by decision-maker i by a set of linguistic terms, such as E_{ij}= {*bad, average,*

[17] "Attention is intentional perception" [Racine+ 2012].

good}. Then, for example, the evaluation of p_{ij} (the perceived value of variable j by decision-maker i), noted e_{ij}, is equal to 100% *bad*.

The set of linguistic terms to qualify the same variable might be different for all the decision-makers. The representation of these linguistic terms in a formal language allows logic operators to be applied to evaluate them. Fuzzy sets [Zadeh 1965] are not sharp-edged, contrary to classical sets whose borders are strict and do not allow an object to be located at the border between two sets. For this reason, the qualifier linguistic terms that express the evaluations of variables can be modelled by fuzzy sets. The gradual membership functions allow a value to belong to each set, which represents a linguistic term, to a certain degree. For example, the value of the variable of the altitude of a mountain can vary between 500 meters and 8848 meters. The value of this variable could be evaluated by a set of qualifier linguistic terms such as *low*, *medium*, *high*, *very high*. Each linguistic term can be presented by a fuzzy set with a membership function. While classical membership functions of the classical sets can only have 0 and 1 as values, the membership functions of the fuzzy sets can have a value in [0,1]. The output of the evaluation process of 3,000 m could be as follows: 0% *low*, 60% *medium*, 30% *high* 0% *very high*.

In this way, the output of the evaluation is a vector $[\boldsymbol{e}_{ij}]$ whose components are the degrees of membership to the fuzzy sets of qualifier linguistic terms, which express the evaluation of p_{ij} by decision-maker i. The vector $[\boldsymbol{e}_{ij}]$ is the input of the reasoning process.

5.5.4.3 Reasoning

"Reasoning consists in the application of mental inference rules to the premises and conclusion of an argument" [Rips 1994], where inference rules are the "principles of reasoning" applied to draw a conclusion from some premises, meaning some hypotheses or assumptions [Veerarajan 2006]. Reasoning creates new knowledge from information, through inference rules (see distinctions between information and knowledge in section 5.5.2). In this step, information perceived and evaluated in the previous steps is transformed into knowledge about a given situation.

Decision-maker i measures how the variables, evaluated separately in the previous step, globally satisfy him. To measure his satisfaction, decision-maker i applies a set of inference rules noted R_i. These inference rules are based on his knowledge K_i, his experiences Exp_i, using his memory M_i, depending on his psychological properties or states Ψ_i, and considering his responsibilities Res_i.

The inference rules, used to reason, might be implicit for a decision-maker and can be different from the rules used by the other decision-makers. Formalizing the reasoning process helps make these rules explicit and consequently, highlights these differences. Human inference rules are not binary and strict.

A fuzzy inference rule has a if-then form such as: if x is A and y is B, then z is C, where A, B, and C are, respectively, fuzzy subsets of the universes X, Y, and Z. "A fuzzy inference rule is interpreted mathematically as defining a mapping from fuzzy subsets to fuzzy subsets" [Sangalli 1998]. "Fuzzy inference is a method that interprets the values in the input vector and, based on some set of rules, assigns values to the output vector" [18]. A Fuzzy Inference System (FIS) consists of [Sivanandam+ 2006]:

[18] Source: http://www.mathworks.fr

- a set of fuzzy inference rules called a rule base,
- the membership functions of the fuzzy sets used in the fuzzy rules, called a data base,
- a fuzzification operation which transforms the crisp inputs into "degrees of match with linguistic values",
- a decision-making unit which performs the inference operations on the inputs,
- a defuzzification operation which transforms the fuzzy results into crisp outputs[19].

A FIS makes it possible to create non-binary rules, based on the fuzzy sets that represent the qualifier linguistic terms. Therefore, a FIS is applied to model the creation and the aggregation of the rules used by each decision-maker.

Decision-maker i uses a set of linguistic terms, noted D_i, and a set of inference rule, noted R_i, to qualify a perceived and evaluated situation $[\boldsymbol{e}_{ij}]$. The inference rule number k, where $1 \leq k \leq |R_i|$, created by decision-maker i, noted $rule_{ik}$, is defined as follows:

$$R_i : \prod_{j=1}^{n} E_{ij} \to D_i, \quad \forall i \text{ and } \forall k, \tag{5.1}$$

$$rule_{ik} : (e_{i1}, \ldots, e_{ij}, \ldots, e_{in}) \to r_i,$$

where r_i is a fuzzy set, representing a qualifier linguistic term in D_i.

For each input (situation) such as $[\boldsymbol{e}_{ij}]$, several rules could be activated with different degrees. The aggregation of these rules gives a result (r_i) for the reasoning process of decision-maker i about a given situation. The r_i is not a vector but a qualifier linguistic term that expresses the appreciation of the situation by decision-maker i. It represents his new knowledge about this situation thanks to his reasoning. The r_i is then the input of the individual decision.

5.5.4.4 Projection of future

Each decision-maker imagines the *good* and *bad* consequences of each option for himself, others, and the enterprise. Construction of the image of the future state of a situation, like the other ISA processes, depends on M_i, K_i, Exp_i, Ψ_i, and Res_i. But, according to some experts, the role of past experiences is crucial in projection of future.

In this step, the result of the reasoning is examined. The output of this step is as follows (see fig. 5.7):

- arrow number 1: either the decision-maker comes back to the reasoning rectangle to question / modify his reasoning, noted r_i?, until the consequences can be assumed and the individual opinion, noted o_i, can be formed,
- arrow number 2: or the decision-maker confirms his reasoning and shapes his opinion of the situation (o_i) which is the output of this step.

[19] For the examples which illustrate the framework of the Choice stage, we have constructed the fuzzy inference rules and for the last three items, we use MATLAB® Fuzzy Toolbox.

5.5.4.5 Individual position

At one point, the loop and interchange between reasoning and projection of the future will result in forming an opinion regarding the decision. In this step, the decision-maker examines his opinion (o_i) and takes a position, noted d_i. Three outputs are then possible:

- either the decision-maker is not satisfied with his opinion o_i that is weakened and questioned, noted o_i?, and the ISA is reiterated (see arrow 3 in fig. 5.7),
- or the decision-maker is satisfied with his opinion and takes a position. But before the decision meeting:
  - either the decision-maker meets other decision-makers through the corridor phase - before meeting and receives information about their positions (see arrow 4 in fig. 5.7),
  - or the decision-maker does not meet the others and goes directly to the next rectangle, namely debate in meeting (see arrow 5 in fig. 5.7).

Individual position, such as the other rectangles in the ISA, is influenced by M_i, K_i, Exp_i, Ψ_i, and Res_i. It marks the end of the ISA wherein each individual forms his opinion and takes a position in a given situation, considering the balance of benefit-risk of the options.

5.5.5 Description of the model - third level - CSA

The (blue) dotted square, on the right of the fig. 5.7 shows the cognitive processes of the CSA process: corridor phase - before meeting, debate in meeting, collaborative decision-making in meeting, and corridor information - after meeting.

5.5.5.1 Corridor phase - before meeting

Unofficial discussions, called corridor discussions, are those that take place out of a Go / No Go meeting. This phase can potentially re-enforce or question the individuals' positions. In this step, beliefs and doubts are shared between the individuals. New information about the position of a colleague may trigger individual reflection. The input of the corridor phase - before meeting is a vector composed of the positions of decision-makers who meet each other before the meeting, noted $[\boldsymbol{d}_i]$, and its output for each decision-maker is a binary value, meaning trigger or not the ISA :

- either the decision-maker reiterate his ISA process to question / modify his position (d_i?), taking into account new information about the positions of the other colleagues (see arrow 6 in fig. 5.7),
- or the decision-maker does not question his position and goes to the next rectangle, namely debate in meeting (see arrow 7 in fig. 5.7).

5.5.5.2 Debate in meeting

A decision meeting is composed of two phases. First, decision-makers debate and exchange their positions on decision, trying to share their beliefs and to persuade each other. In this step, the group's opinion, noted o, about a given situation begins to be shaped. The input is the positions of the m decision-makers, noted $[\boldsymbol{d}_i]$. As any other collaborative step, new information on the interpretation or position of a colleague may either trigger the ISA of decision-maker i (see arrow 8 in fig. 5.7) or not. In the latter case, decision-maker i does not (re)examine his position and accompanies the group to the next rectangle (see arrow 9 in fig. 5.7).

5.5.5.3 Collaborative decision-making in meeting

Collaborative decision-making aims at reaching a compromise between decision-makers. This process is influenced by interactions between different decision-makers. In a complex and multidisciplinary decision-making process, the roles and weights of decision-makers in the decision-making are not equal, depending on the composition of the group, the hierarchical position of each decision-maker, his expertise levels, experiences, the phase of the project, etc.

We again need inference rules in order to formalize this inequality which is, like the variables, qualified in the real world by linguistic terms such as "decision-maker i has a strong influence on the decision-making in this phase of the project". These expressions create the rules that determine the weight of decision-makers in a collaborative decision. The CSA allows us to define and formalize these rules and consequently highlights these difference roles.

As explained for the reasoning process, in section 5.5.4.3, human inference rules are not binary and strict and in enterprises the different weights given to different experts are often implicit within a decision group, even if probably every decision-maker knows them. Again a Fuzzy Inference System (FIS) makes it possible to express the non-binary rules about the weights of decision-makers, based on fuzzy sets that represent the qualifier linguistic terms. Additionally, fuzzy sets and a FIS have respectively been used to model the evaluation and reasoning steps. Thus, using a FIS to model the collaborative decision-making step facilitates connection between these steps. In this regard, a FIS is applied to reproduce the collaborative decision.

The group of decision-makers use a set of linguistic terms, noted D, and a set of inference rules, noted R, to qualify a perceived and evaluated situation $[\boldsymbol{e}_j]$. The inference rule number l, where $1 \leq l \leq |R|$, noted $rule_l$, is defined as follows:

$$R : \prod_{i=1}^{m} D_i \to D, \qquad (5.2)$$
$$rule_l : (d_1, \ldots, d_i, \ldots, d_m) \to d,$$

where d is a fuzzy set, representing a qualifier linguistic term in D.

For each input $[\boldsymbol{d}_i]$, several rules could be activated with different degrees. The aggregation of these rules gives a result where its value for a given situation is a degree of membership to the linguistic term represented by d. For example, it can be a 90% *good* situation which translates through a defuzzification to a possible option of the collaborative decision *i.e.* Go.

5.5.5.4 *Corridor information - after meeting*

After the meeting, decision-makers continue to talk about the decision in the corridor phase - after meeting. The input of this step is the collaborative decision made, d.

The difference between the collaborative decision (d), and an individual position (d_i), expresses the degree of dissatisfaction of this decision-maker: $\delta_i = |d - d_i|$, where δ_i is a fuzzy set representing the linguistic term that expresses the difference between the individual position of DM_i, meaning d_i, and the collaborative decision of the group, meaning d. The set of all δ_i is called Δ_i.

The discussion of the corridor phase:

– either questions d and increases δ_i, then the ISA is again triggered for decision-maker i (see arrow 10 in fig. 5.7). But this time, the ISA is not necessarily followed by the CSA if the d is maintained by the group. Then, after this ISA process, either decision-maker i accepts the decision made and maintained by the group or intends to change it (see arrow 12 in fig. 5.7),

– or reinforces d and reduces δ_i, then the decision is confirmed / accepted and the Choice stage ends (see arrow 11 in fig. 5.7).

The dissatisfaction index is used to measure the risk of invalidating a decision made.

5.5.6 Index of decision invalidation

If the dissatisfaction index is high for several decision-makers, especially those who have an important influence, the decision may be invalidated in time. It does not mean that if all the decision-makers agree, the decision is *good*. It helps measure the risk of conflict and invalidating a collaborative decision made and thus the delays in decision.

The index of decision invalidation for decision d, noted δ, can be qualified by a set of linguistic terms, noted Δ, and can be obtained using a FIS based on a set of inference rules, noted L. The inference rule number p, where $1 \leq p \leq |L|$, noted $rule_p$, is defined as follows:

$$L : \prod_{i=1}^{m} \Delta_i \rightarrow \Delta, \tag{5.3}$$
$$rule_p : (\delta_1, \ldots, \delta_i, \ldots, \delta_m) \rightarrow \delta.$$

where δ is a fuzzy set, representing a qualifier linguistic term in Δ.

In the next section, we apply the framework of the collaborative choice to an illustrative simplified example of a Go / No Go decision.

5.5.7 Application of the framework to a simplified Go / No Go decision

As we have seen in section 1.2.2 on page 16, a Go / No Go decision depends on a great deal of information about the properties and behavior of a new developing compound which determines its benefit-risk balance. In order to give an illustrative and understandable example which remains representative of a real situation, we illustrate the framework *via* a simplified application case on the Go / No Go decision milestone of phase II. The purpose of this example is: 1) to show how the framework of the collaborative Choice stage helps to understand and explain different information processing of the same information by different experts, 2) how decisions made by two groups composed of the same decision-makers are different, according to the importance given to different experts in each group, and 3) to study and analyze previous conflicts in past decisions and be able to anticipate future conflicts, meaning when a decision is at risk of invalidating [Hassanzadeh+ 2011b].

The main goal of the tests of phase II is to establish the efficacy and safety windows of the compound in the target population (patients), by identifying the minimal effective and the maximal tolerated doses on this population [Julious+ 2010]. The transition to phase III implies taking risks with human health and involves an important time and financial investment. Therefore, a great importance is attached to the Go / No Go decision at the end of phase II. Invalidating the Go / No Go decision of the end of phase II, *a posteriori*, would have serious consequences for the enterprise *e.g.* a sharp instantaneous fall in the share price. The choice of the Go / No Go decision at the end of phase II has thus been motivated by its importance. Additionally, at the end of phase II, the results of the tests are partially available for the following three criteria: safety, efficacy, and quality. This helps us create a simple example without detailed data on the numerous tests for each of these criteria.

The first assessment of efficacy is made in phase II. The minimal tolerated dose was previously documented on healthy volunteers (aim of the studies of phase I). Therefore, in phase II, tolerance and efficacy can both be evaluated, which define the first two variables of our example: *Tolerance* which is the main measure of safety and *Efficacy*, which, as its name implies, is the measure of effectiveness. Another parameter that is evaluated is the Cost of Good (COG) based on the cost of chemical development. *COG* is one important measure of the quality of a molecule and is the third variable of our example. In this way, the Go / No Go decision milestone at the end of phase II is based on three uncertain variables: *Tolerance*, *Efficacy*, and *COG*.

In order to make this example "manageable" (see the description of Albright 2011 in section 3.2.3 on page 51), we state some assumptions concerning the Go / No Go decision at the end of phase II:

Assumptions in the example

- it is supposed that there is not any toxicity or kinetics alert in the results of previous tests that prevents starting phase II,
- the project manager, who has aggregated the results of the tests, sends only these three variables to the experts of the steering committee. In reality, a Go / No Go decision is based on the hundreds of qualitative and quantitative pieces of information which are sent and presented to the steering committee with different levels of interpretation, regarding the raw data. We take into account only three variables, supposing that the other variables, studied in this phase, such as the stability of the compound and its metabolism are incontestably good,
- the interdependencies between the variables are not taken into account,
- the steering committee is composed of only[20] three decision-makers: a toxicologist, a clinician, and an economist, respectively noted DM_1, DM_2, and DM_3,

[20] In reality, steering committees are often composed of several multidisciplinary experts.

– the same decision-makers form two groups where the importance given to the economist's position is more in one of these groups, while the toxicologist and the clinician have the same roles in the both groups[21].

The input vector is:

$$[\boldsymbol{v}_i] = (v_1, v_2, v_3) = (\textit{Tolerance, Efficacy, COG}). \tag{5.4}$$

Tolerance and *Efficacy* can have a value between 0 and 200 mg and *COG* can have a value between 0 and 10,000 €/kg. For *Tolerance*, a high value is appreciated meaning a higher quantity of the compound can be tolerated, while for *Efficacy*, a low value is preferable meaning a less quantity of the compound is effective. *COG* can still be reduced, while *Tolerance* and *Efficacy* often cannot be changed at this phase.

The decision-makers decide[22] whether: 1) to continue the project, if they find the results *good*, or 2) to put the project on standby, if the results are not conclusive enough and complementary studies are requested. Standby implies delay. It is somehow as if a Go or No Go decision has not been made yet, or 3) to stop the project, if the results are *bad* enough. Thus, the output is one of these options: Go, Standby, or No Go. Each cognitive process is now explained for the three decision-makers and the risk of invalidating the decision is calculated.

5.5.7.1 Perception

The value of each variable is perceived by each decision-maker and is transformed into meaningful data. Perception works as a filter. Supposing that all variables are meaningful for DM_1 and DM_2, but v_2 is not meaningful to DM_3. Thus, DM_3 does not retain it. The outputs of DM_1, DM_2, and DM_3 are as follows, where the long dash shows that the DM_3 did not perceive the second variable:

$$[\boldsymbol{p}_{1j}] = (p_{11}, p_{12}, p_{13}), \tag{5.5}$$

$$[\boldsymbol{p}_{2j}] = (p_{21}, p_{22}, p_{23}), \tag{5.6}$$

$$[\boldsymbol{p}_{3j}] = (p_{31}, \text{—}, p_{33}). \tag{5.7}$$

5.5.7.2 Evaluation

The knowledge of each decision-maker helps him evaluate the perceived variables, in terms of satisfaction of his own criteria. The toxicologist, DM_1, knows that if more

[21] It should be noted that, if the toxicologist finds a compound toxic and dangerous, a No Go decision is made immediately. If the toxicology findings are *satisfactory*, then the competitiveness of the compounds compared to existing drugs is discussed by the experts and toxicologist and clinician have the same weighting.

[22] Referring to the proposed typology of uncertainty factors in section 2.1.4 on page 29, the three types of uncertainty factors affected this decision-making: 1) factors relating to the object: in spite of the obtained results, the behavior of the compound is not completely predictable, 2) factors relating to the subject: the uncertain results of the tests are perceived differently according to the personality, psychological properties, previous experiences, and speciality of each decision-maker. The results of the tests, carried out on a limited number of patients, cannot be generalized to the whole target population, 3) factors relating to the context: in a competitive industrial context, is the compound more effective, better tolerated, or less expensive than the existing or competing products?

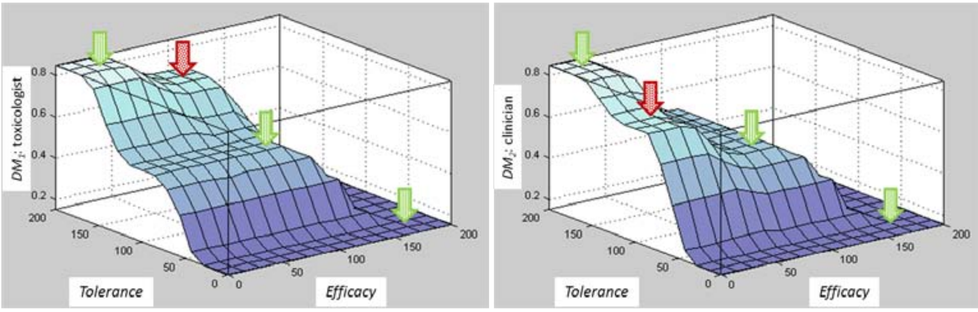


Figure 5.8: Surfaces of the result of the reasoning process for DM_1 and DM_2

than 200 mg of the new compound is tolerated, then *Tolerance* is unquestionable. The clinician, DM_2, knows that if less than 50 mg of the new compound has a significant difference on *Efficacy*, compared with the placebo group, it is unarguably effective. The economist, DM_3, knows if the *COG* is less than 2500 €/kg, it is obviously good.

The toxicologist, DM_1, is more demanding about *Tolerance* which is in the scope of his expertise and responsibilities and finds it *average*. His evaluations of two other variables is *good*. The clinician, DM_2, evaluates the given values for *Tolerance, Efficacy, COG*, respectively, *good, average, good*. In other words, he finds *Efficacy, average*, but *Tolerance* and *COG good*. The economist, DM_3, did not pay attention to the v_2, meaning *Efficacy*, in the previous step. He finds *Tolerance good*, and *COG average*. Thus, in the same situation, DM_1 and DM_2 evaluate all variables, and DM_3 evaluates the variables that he retained:

$$[\boldsymbol{e}_{1j}] = (e_{11}, e_{12}, e_{13}) = (\textit{average, good, good}), \tag{5.8}$$

$$[\boldsymbol{e}_{2j}] = (e_{21}, e_{22}, e_{23}) = (\textit{good, average, good}), \tag{5.9}$$

$$[\boldsymbol{e}_{3j}] = (e_{31}, \text{—}, e_{33}) = (\textit{good,—,average}). \tag{5.10}$$

5.5.7.3 Reasoning

In this step, we model the behaviors of decision-makers in a situation of decision-making by using inference rules. The reasoning process is based on the inference rules used by the decision-makers to relate their isolated evaluations of different variables. The results of the reasoning process give the reasoning of the decision-makers, noted r_1, r_2, and r_3. These results are expressed, as the evaluation of the all variables, by qualifier linguistic terms. As we have seen in the evaluation process, *Tolerance* and *Efficacy* are respectively more important to DM_1 and DM_2. This difference is expressed through two different rules (see function 5.1):

$$rule_{11} : (\textit{good} \wedge \textit{average} \wedge \textit{average}) \rightarrow \textit{satisfactory}, \tag{5.11}$$

$$rule_{21} : (\textit{good} \wedge \textit{average} \wedge \textit{average}) \rightarrow \textit{average}. \tag{5.12}$$

Some rules are commonly used by both decision-makers DM_1 and DM_2, noted $rule_{com.12.s}$ where s is the number of their common rules:

$$rule_{com.12.1} : (\textit{good} \wedge \textit{good} \wedge \neg \textit{bad}) \rightarrow \textit{good}, \tag{5.13}$$

$$rule_{com.12.2} : (\textit{average} \wedge \textit{average} \wedge \textit{good}) \rightarrow \textit{average}. \tag{5.14}$$

Some rules are commonly used by all the decision-makers, noted $rule_{com.t}$ where t is the number of these common rules:

$$rule_{com.1} : (\textit{bad} \wedge \text{—} \wedge \text{—}) \rightarrow \textit{bad}, \tag{5.15}$$

$$rule_{com.2} : (\textit{good} \wedge \textit{good} \wedge \textit{good}) \rightarrow \textit{good}, \tag{5.16}$$

$$rule_{com.3} : (\textit{average} \wedge \textit{average} \wedge \textit{average}) \rightarrow \textit{average}. \tag{5.17}$$

The first rule, $rule_{com.1}$, means that if *Tolerance* is *bad*, meaning the compound is toxic, its development is stopped regardless of the two other variables. It might be different for some special classes of drugs such as the anti-cancer medicines.

Fig. 5.8 illustrates the impact of this difference of points of view on the outputs of the reasoning. The surface of the reasoning processes of DM_1 and DM_2 are respectively presented on the left and right. As explained in section 5.5.7, *Tolerance* and *Efficacy* vary between 0 and 200 mg and a high value is appreciable for *Tolerance*, while a low value is expected for *Efficacy*.

The (green) striped arrows indicate the parts of the surfaces of the reasoning process wherein both DM_1 and DM_2 agree *i.e.* when:

- *Tolerance* is high, meaning a high quantity of the compound is tolerable, and *Efficacy* is low, meaning a low quantity of the compound is effective, then the result of the reasoning is high for both DM_1 and DM_2,
- *Tolerance* is low, meaning only a low quantity of the compound is tolerable, and *Efficacy* is high, meaning a high quantity of the compound is needed to be effective, then the result of the reasoning is low for both DM_1 and DM_2,
- *Tolerance* and *Efficacy* are both average, then the result of the reasoning is average for both DM_1 and DM_2.

The (red) pointed arrows indicate the parts of the surfaces of the reasoning process wherein DM_1 and DM_2 do not agree *i.e.* when:

- on the left, DM_1 is more demanding about *Tolerance* than *Efficacy*: where *Tolerance* takes the values near to 100 mg, *i.e.* the average values, the surface of the reasoning process of DM_1 drops, even if *Efficacy* has a value less than 50 mg, meaning that the compound is "very" effective,
- on the right, contrary to DM_1, for DM_2 *Efficacy* is more important than *Tolerance*: where *Efficacy* takes the values near to 100 mg, *i.e.* the average values, the surface of the reasoning process for DM_2 drops, even if *Tolerance* attains 200 mg, meaning that the compound is "perfectly" tolerable.

5.5.7.4 Projection of future

As explained in section 5.5.4.4, the result of the reasoning can be reinforced or be questioned when decision-makers project into the future. In this example, we supposed that the reasoning of all the decision-makers are confirmed in this step.

Table 5.3: Simulation results

	DM_1	DM_2	DM_3	G_1	G_2
$[50, 180, 9500]$	0.15	0.15	0.15	No Go	No Go
$[200, 25, 1000]$	0.84	0.84	0.84	Go	Go
$[190, 40, 2500]$	0.84	0.84	0.71	Go	Go
$[200, 25, 5000]$	0.84	0.84	0.50	Go	Go
$[130, 90, 4100]$	0.50	0.50	0.50	Standby	Standby
$[130, 35, 5500]$	0.55	0.72	0.50	Go	Standby
$[190, 100, 4900]$	0.70	0.50	0.50	Go	Standby

5.5.7.5 *Individual position*

Taking a position regarding the decision to be made is strongly affected by individual factors such as personal risk aversion and taste for risk which can lead to a situation appreciated as *average*, ending up respectively as a No Go and Go option. The three decision-makers do not review their ISA processes and do not change their individual opinions and their positions are not changed neither during the meeting nor in the corridor phases before and after the meeting.

5.5.7.6 *Collaborative decision-making*

In this step, we show how decisions made by two groups, noted G_1 and G_2, composed of the same three decision-makers DM_1, DM_2, and DM_3, vary according to the importance given to decision-makers in each group. In G_1, the importance given to the positions of DM_1 and DM_2 is equal, while the position of DM_3 has less importance compared to the first two decision-makers. In G_2, the importance given to the positions of all decision-makers is equal. The two groups have to make the Go / No Go decision, based on the same information, at the end of the phase II.

Tab. 5.3 shows the individual positions and the collaborative decisions of phase II, made by G_1 and G_2, simulated by a FIS as explained in previous sections. The first column comprises the input vectors. Each vector includes three components *e.g.* [*Tolerance, Efficacy, COG*]=[50 mg, 180 mg, 9500 €/kg]. The inputs have been chosen to study the behavior of the model regarding: 1) the behavior of each decision-maker and 2) the behavior of each group. The cognitive processes of the ISA are applied to each input for the three decision-makers. The columns 2, 3, and 4 represent the individual positions of the decision-makers. We use a simple defuzzification operation as follows: values less than 0.4 are transformed to a No Go decision, values between 0.4 and 0.60 to Standby, and values more than 0.60 to a Go decision. The two last columns show two collaborative decisions of the groups G_1 and G_2 (see function 5.2). Individual position of the decision-makers and collaborative decisions of the groups have values between 0 and 1.

In this regard, the first input represents a *bad* result: an intolerable, ineffective, and high-cost compound. Everyone agrees to stop its development. The decisions

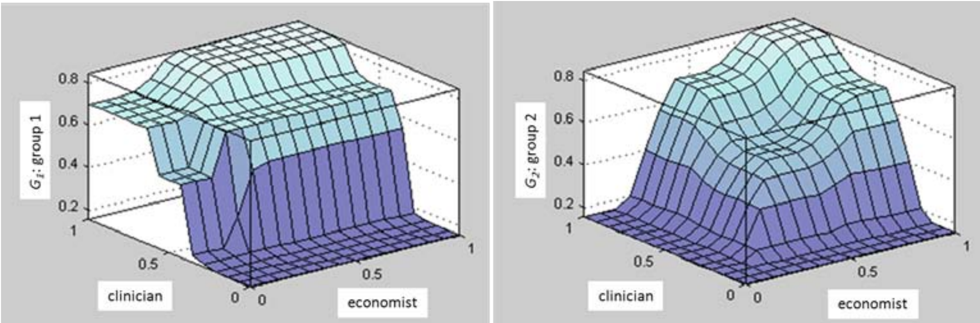


Figure 5.9: Surfaces of the result of the collaborative decision-making process for G_1 and G_2

of the both groups are No Go. The two following inputs represent *good* results: tolerable, effective and not expensive compounds. Thus, the decisions of the both groups is Go. In the fourth raw, *Tolerance* and *Efficacy* are *good*, while *COG* is *average*. The decisions of the both groups is Go, even if the position of DM_3 (economist) is Standby because in all cases *Tolerance* and *Efficacy* are more important than *COG*. In row 5, the results are *average* and everyone agrees to postpone the decision, waiting for more results. In rows 6 and 7, respectively, one of the values of *Tolerance* and *Efficacy* is *good* and the other one is *average*, while *COG* is *average*. In these cases, the decision of G_1, wherein less importance is given to DM_3, is GO. In the same cases, G_2 gives more importance to DM_3 and decides to postpone the project. These simulations validate the coherency of the results produced by the framework for this example.

Fig. 5.9 shows the difference of the position of DM_3 in G_1 and G_2: on the left, in G_1, when the individual position of DM_2 (clinician) is near 0 *i.e.* when he qualifies the situations *very bad*, the collaborative decision is also 0 *i.e.* No Go decisions even if the position of DM_3 (economist) is favorable. On the right, in G_2, the harmonious surface of the collaborative decision-making shows that the clinician and the economist have the same weighting in the collaborative decision.

The example illustrates how the position of each decision-maker within the group can change the collaborative decision for the same situation, made by the same decision-makers.

5.5.7.7 Index of decision invalidation

For a given situation, [170, 30, 8900], the index of decision invalidation is calculated for the decisions made by G_1 and G_2. The results show the dissatisfaction of DM_3 with the decision of G_1 is: $\delta_3 = |d_{G_1} - d_3| = 0.56 - 0.15 = 0.41$, while his dissatisfaction with the decision made by G_2 is: $\delta_3 = |d_{G_2} - d_3| = 0.15 - 0.15 = 0$. Therefore, in the first case, the economist **may** try to invalidate *a posteriori* the decision made by the group.

5.5.8 Questions answered in / arising from the framework of the Choice stage

The proposed framework formalizes the Choice stage, including two "periods" of a collaborative decision-making process which are pointed out by Roy 1996: a period of individual reflection and a period of group interaction.

The individual reflection period, called ISA, is modeled based on the SA model proposed by Endsley 1995 who highlights the cognitive processes used by a decision-maker to reach the state of awareness in order to make a decision. We have enriched the SA model from both theoretical and empirical perspectives: 1) distinctions between data, information, and knowledge allows us to specify the nature of the inputs and outputs of the cognitive processes. It clarifies and formalizes how the same data, throughout the cognitive processes, progressively transforms into different conclusions, 2) thanks to the discussions with our industrial partner and his colleagues in the pharmaceutical industry, two cognitive processes have been added to the SA model: evaluation and reasoning. The first of these evaluates the values of the variables separately and the second makes relationships between the evaluated values of a set of variables and measures how a situation characterized by these values is satisfactory to each decision-maker. Even if in *simple* situations, it seems that evaluation and reasoning happen instantly but they are two distinct functions. In the complex real world, the values of the variables are often evaluated separately and are then related. Therefore, these two processes are necessary to explain the functioning of the decision-makers.

The group interaction is not sufficiently elaborated in the literature. It is either represented as a box in the models (see fig. 5.5) or only differences and similarities of the decision-makers are illustrated and not their interactions (see fig. 5.4). More elaborated models of collaborative decision-making do not take into account the period of individual reflection (see fig. 5.5). Our framework of the collaborative Choice stage takes into consideration both "individual reflection" and "group interaction" (see fig. 5.7) and simulates the decisional behaviors of the individual and groups (see fig. 5.8). In the CSA, we take into account three loops that may trigger the ISA when the decision-makers meet each other: 1) in a corridor phase through unofficial discussions before the decision meeting, 2) during the meeting, 3) in another corridor phase after the meeting. The CSA illustrates how an individual position may be questioned or be reinforced by the influences of the other decision-makers.

Finally, an index is defined to measure the risk of invalidating a decision made *a posteriori*, which is based on the differences of the individual positions and the collaborative decision. This index does not reflect the quality of a decision, but is a measure to predict whether a decision will be accepted or is at risk of being invalidated.

This third and last level of the Go / No Go decision-making process model allow us to understand, represent (visualize), share, and validate a framework of the collaborative Choice stage with the industrial actors. The cognitive processes are highlighted in the framework, but the environmental (contextual), individual, and collaborative factors are not precise enough to study their impacts on the effectiveness and rapidity of decision-making. But the framework can be used as a baseline for discussion with the actors in order to examine which activities of the collaborative Choice stage cause delay in decision-making and what solutions are proposed by the actors. This is the subject of an interview-based approach in the next part.

Conclusion - part II

In this chapter, the Go / No Go collaborative decision-making process is modeled to be analyzed in order to investigate the problem of delay. This model is presented at three levels of detail which are obtained through the refining loop of the modeling process that we propose.

First, a pyramidal form of four macro stages of the decision-making process illustrates the hierarchical structure for the main actors and the information flow: descending information which becomes more detailed from the superior hierarchical levels to the lower levels and ascending information which becomes more aggregated from the lower levels to the superior hierarchical levels. The hierarchical positions of the actors and the information flow are visualized in this pyramid, but the activities of each stage are not sufficiently detailed. A question arises about the role of the aggregation and a possible loss of information in delays in decision-making.

Secondly, a detailed version of these stages in BPM notation allows us to specify the activities and their inputs and outputs, especially the activities performed on ascending information before presentation to the steering committee. It takes into account both descending and ascending information, while the latter, to the best of our knowledge, is less fully considered in the literature. In this level, the collaboration between the actors with different roles in the information life cycle is shown *i.e.* between those who prepare information and those who decide. But the collaboration between the decision-makers in the Choice stage is not clear.

Thirdly, the collaborative Choice stage is represented in a framework which includes both "individual reflection" and "group interaction" [Roy 1996] respectively through an ISA [Endsley 1995] and a CSA. The ISA highlights the transformation of data into information, and then into knowledge through the individual cognitive processes: perception, evaluation, reasoning, and projection of the future. Fuzzy sets and fuzzy inference rules are applied to model human evaluation and reasoning with uncertain values. The CSA represents the interactions between decision-makers through corridor phases (informal discussions), debate (formal discussions), and decision-making itself. An example of the Go / No Go decision at the end of phase II of a pharmaceutical R&D project is presented to illustrate the proposed framework. In sum, the framework: 1) makes explicit inference rules used by decision-makers to take a position before the collaborative steps. It helps analyze their differences and similarities, 2) highlights the interactions within a group which may reinforce or question an individual position, propagating doubts and beliefs, 3) simulates individual and collaborative behaviors depending on the individual cognitive processes and the positions of the individuals in the group, 4) calculates the risk of invalidating a decision by measuring the dissatisfaction of the decision-makers. It helps study and analyze previous conflicts in decisions and anticipate future conflicts, according to the position of each decision-maker and the composition of the group.

However, some questions remain unanswered: how do actors perform their activities (practices)? What are they thinking and feeling about their current practices? What are the role of the influential factors such as "task and environment factors" on their practices? Are their current practices efficient or are some changes necessary to make decisions more effectively and rapidly? The pyramidal form, the model presented in BPMN, and the framework cannot directly answer these questions, but they can be used as the baselines for discussion with the actors in order to collect information about these questions, which is the subject of the next part, through an interview-based approach.

Part III

Collecting and structuring practices

Method, application, and results

Purpose: decision-making in drug development projects implies dealing with a high degree of uncertainty about the benefits and risks of new compounds. Formal methods of decision-aiding reach their limits at decisional milestones wherein decisions depend on the interpretation of the complex and multidisciplinary results by various experts. In the case of Go / No Go decisions, if the results are not conclusive enough, experts may either delay a decision or make and unmake it *a posteriori*. In this chapter, we identify the factors that affect the collaborative decision-making process in an organization. Then, we provide actors with a set of efficient practices that could help them make decisions more effectively and rapidly.

Design/methodology/approach: two approaches are used in this research: a literature review and a field study through an interview approach.

Findings: our research provides a consistent and reproducible method to assess the causes of delay in decisions and the efficient practices required to control them. It first includes the construction of an interview grid to conduct in-depth interviews and then, a plan of analysis of interview results. This method is applied to our field study. Two groups of major actors in Go / No Go decision-making are identified and interviewed: project managers and decision-makers. The results show all the interviewees agree that Go / No Go decisions are frequently delayed or invalidated. Fear of uncertainty, fear of hierarchy, and the difficulty of No Go decisions are the three most frequently mentioned factors involved in decision delays. The two activities in the decision-making process that are most cited by the interviewees are firstly, the Preparation and presentation of results, and secondly, Collaborative decision-making. The same tendency is observed with both project managers and decision-makers. We conclude that although much attention is quite rightly paid to the way in which the tests are performed and the results are provided, little attention is given to the way in which the results are aggregated, prepared and presented, and to how the decisions are made. In sum, Preparation and presentation of results and Collaborative decision-making are presumed to be *natural* activities that do not need training, practice, or even the necessary time to be performed. We thus present here some efficient practices to help improve these activities.

Originality/value: indecision has mostly been studied in its individual dimension in clinical psychology, vocational choice, and marketing. The collaborative, and especially the organizational dimensions of indecision have not been closely examined in the literature. Our study concerns the problem of delay at a high level of decision-making in pharmaceutical R&D projects, an area that is not easily accessible. The actors who contribute to Go / No Go decisions have a high level of expertise and are few in number. They work on very sensitive subjects that have a direct influence on public health and on the share prices of companies. Additionally, they work in a very competitive sector which implies a high level of confidentiality. Therefore, this thesis, thanks to our industrial partner, has access to very sensitive information. Another particularity of this research context is the notion of non-emergency, which is again not widely covered in studies of decision-making. The assumption is that if we are able to make decisions in emergency situations, such as a crisis, we are able to make them in non-emergency situations. Our study shows that the non-urgent nature of a situation does not actually facilitate decision-making. We investigate the problem of delay through an exploratory approach based on in-depth interviews. A method is proposed to annotate and analyze the interview results which allows us to find 252 factors that affect the decision-making process. These results have been obtained in collaboration with the major actors of the pharmaceutical industry, without influencing them as could have been the case in a multiple-choice studies. The proposed method seems appropriate for other industrial sectors.

Research limitations: as with all interview-based approaches, the subjectivity of the interviewers and interviewees is an unavoidable weakness. We have tried to reduce it by cross-referencing opinions, pointing out clearly their convergences and divergences. The results are limited to the problem of delay in difficult Go / No Go decisions in the pharmaceutical industry. The sample only covers the R&D actors who contribute to these decisions.

Introduction - part III

The safety, efficacy, and quality of potential new medicines are examined several times by a group of actors throughout a R&D project. Each examination is based on the results of the tests on the new molecule and ends in a Go / No Go decision which determines the continuation or stopping of the project. If the results conclude that the molecule is toxic, a No Go decision is *rapidly* made. Idem, when the results are very *good*, a Go decision is *rapidly* made. The problem is that sometimes the results of the tests are not conclusive enough to make a Go / No Go decision by a multidisciplinary group of various experts who differently perceive and interpret the complex and uncertain results. In these latter cases, Go / No Go decisions are frequently delayed. Meetings can be held and re-held without a clear decision being made. In the competitive context of the pharmaceutical industry, like in other industries, it is important to make decisions effectively and rapidly in order to launch a new product before your competitors do.

In the literature, "there is a large body of research on when and how we make decisions, but little on when and why we do not make them" [Brooks 2011]. The actors in drug development projects complain of delays in the decision-making process in a general manner. However, little is known about their current practices and their experiences.

The purpose of this part is to answer the questions that were raised in the first two parts (see section 2.3 on page 37 and section 5.5.8 on page 103): why are some difficult Go / No Go decisions frequently delayed? What are the current practices used to make collaborative decisions? Are they efficient or are some changes necessary?

First, the notion of efficient practice and how it can improve performance is reviewed in chapter 6. Then, in chapter 7, we explain our methodology to investigate the causes of delay and efficient practices to reduce delay in collaborative decision-making when faced with uncertainty. Finally, in chapter 8 this methodology is applied to the problem of delay in Go / No Go decisions, and the results are presented and discussed.

6

Efficient practices in decision-making

Efficiency is doing things right. Effectiveness is doing the right thing.
Zig Ziglar

In this chapter, first, the necessity and importance of efficient decision practices is discussed. Secondly, the means of identification and implementation of efficient practices, and potential barriers to their implementation are briefly reviewed.

6.1 Necessity and definitions of efficient practices

In a competitive industrial world, it is of strategic importance for an organization to adopt "best" practices to be more effective and more rapid [Xu+ 2012]. In the literature, the notion of practice is usually accompanied by adjectives such as best, good, effective, or efficient, to qualify a manner of doing something. Xu+ 2012 give a broad definition of "best" practices, as "a technique, method, process, activity, or mechanism" to optimize results and minimize mistakes, focusing on the results. For some authors, optimization is related to the ways of performing a process to obtain high performance [Bogan+ 1994]. “As a business buzzword, best practices are commonly used to describe the most efficient and effective way of accomplishing a task or achieving a goal” [Engle 2008]. Kreitz 2008 adopts the definition of Webster’s New Millennium® Dictionary[1] which relates a best practice to the circumstances: “a practice which is most appropriate under the circumstances, especially as considered acceptable or regulated in business; a technique or methodology that, through experience and research, has reliably led to a desired or optimum result.”

A compendium of efficient practices proposes a set of "expected activities" which have already proved their efficiency and relevance in a field. This vision connects efficient practices and feedback, and consequently knowledge management [Penide 2011]. In this definition the notions of practice and activity are used equivalently. Admittedly, a practice (way of performing an activity) is often[2] described through the recommended activities, for example, “use formal performance system” or “establish risk management” [PMI 2003]. Deguil 2008 represents a business process, its activities, and their associated efficient practices in fig. 6.1. It visualizes the

[1] Webster’s New Millennium® Dictionary of English, Preview Ed. (v. 0.9.7), Lexico, http://dictionary.reference.com/browse/best+practice

[2] Efficient practices are sometimes listed as factors: "effective communication" or "customer satisfaction" [Loo 2002].

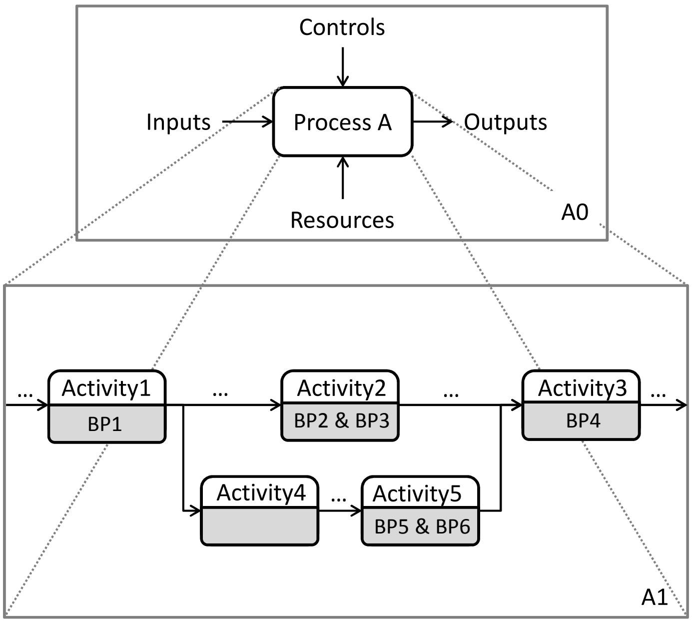


Figure 6.1: Representation of the relationship between activities and "best" practices, noted BP [Deguil 2008]

relationship between activities and the practices and helps distinguish the main activities of the process and practices even if they are described as "expected activities".

Establishing databases of best practices helps store lessons learnt and makes them accessible to others [Gunday+ 2011]. Efficient practices can be identified through brainstorming [PMI 2003] and a “systematic and careful reflection on hard-won practical experience” [Kreitz 2008]. They are derived from "numerous success or failure experiences" over time. The sources of efficient practices can be found in “industrial experiences (*e.g.* practitioners, company hand-books), consulting experiences (*e.g.* experts), advanced information systems (*e.g.* enterprise resource planning systems, technology providers) and knowledge bases (*e.g.* literature, field studies, conferences and workshops)” [Xu+ 2012].

Practices are studied in various fields: in information systems through the Capability Maturity Model Integration (CMMI®)[3] by the Software Engineering Institute (SEI), in manufacturing [Vastag+ 2003; Ungan 2005], in supply chain management [Li+ 2006], in risk management [Wyk+ 2008], in human resource management [Bellini+ 2008], in business process redesign [Reijers+ 2005], in total quality management and Six Sigma [Taylor 1998], in performance evaluation [Chen+ 2007], in innovation management [Aït El Hadj+ 2006; Boly 2008; Ferchichi 2008; Midler+ 2012; Jullien+ 2012], in innovation management under resource constraints [Penide+ 2012], and in project management through the Project Management Body of Knowledge (PMBOK®)which is a recognized standard guide for the project management profession (first version, [PMI 1983]) and the Organizational Project Management Maturity Model (OPM3®) [PMI 2003]. The PMBOK® includes proven practices of management of the scope, time schedule, cost, quality, human resources, communications, risk, and procure-

[3] http://www.sei.cmu.edu/cmmi/

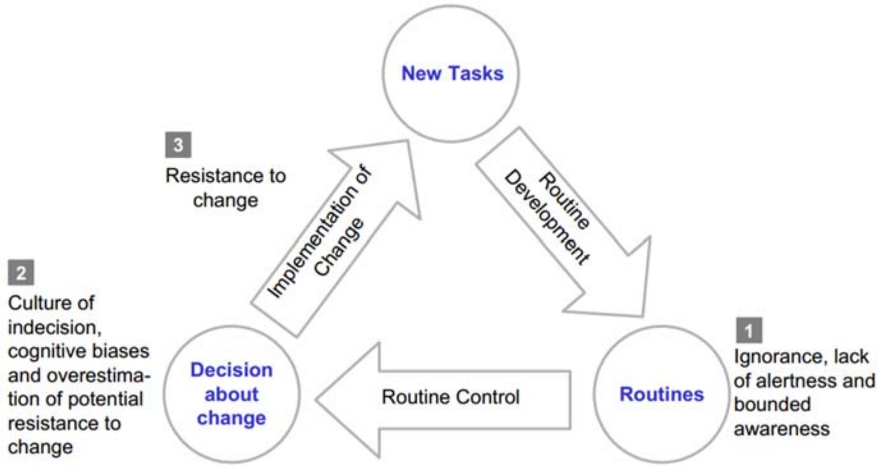


Figure 6.2: Routine-based view of the process of / obstacles to organizational change [Kesting 2007]

ment, among five groups of processes: initiating, planning, executing, monitoring and controlling, and closing.

In the pharmaceutical industry, efficient practices are studied in research, development, fabrication, and commercialization phases for laboratory activities, clinical studies, fabrication, and distribution [Fabre 2004]. The *classic* practices of cost, resource, and time management are also implemented for these activities. But, the *classic* practices of project management manuals do not focus on delay in decision-making. We seek to investigate efficient practices in decision-making when faced with uncertainty, in a multidisciplinary field that implies the collaboration of various experts with their different perceptions of information that becomes progressively more accurate.

6.2 Difficulties of implementing efficient practices in enterprises

Efficient practices should be implemented according to their importance and achievability [Xu+ 2012]. The importance can be related to practicality and feasibility as well as to resource constraints *i.e.* what would be suitable and what would be possible to do, in the light of the constraints. The crucial role of culture in implementation of efficient practices is emphasised by several authors. Efficient practices emerge in an organizational culture that values and nurtures these practices [Cooper 1998; Kerzner 1998; Charan 2001; Loo 2002; Davenport 2009]. Repetition can help change behaviors [Charan 2001] and found a culture. Establishing changes in a culture implies studying possible obstacles.

Ungan 2005 indicates that companies are generally not successful in implementation of the efficient practices identified when adequate support for these practices is not provided. In management literature, some barriers to implementing efficient practices are mentioned, such as:

– ignorance and lack of alertness: "a precondition for any change, firms have to realize that there is something to change" [Kesting 2007],

- difficulties with the decision about change: Kesting 2007 explains the routine-based view on the process of organizational change (see fig. 6.2) which includes:
  - a "culture of indecision" based on the explanations of Charan 2001: new ideas "die" because of indecision and inaction,
  - cognitive biases concerning decision-making about changes in established routines: tendency for the alternatives that justify, favor, and perpetuate the existing situations,
  - inaccuracy in estimation of potential resistance: it is often difficult to estimate the consequences of the changes and consequently the resistance to it, since this involves predicting future reactions,
- resistance to changes: Loo 2002 explains two causes for this resistance: 1) either because manager and staff do not see the need (which ties in with the ignorance and lack of alertness mentioned by Kesting 2007), or 2) they are not prepared for changes,
- absence of a project management "champion": who would push for the implementation of the practices (may be the most mentioned obstacle) [Loo 2002],
- time pressures and constraints: "everyone is already busy and improvements would require allocating even more time and energy into work at the expense of personal and family time" [Loo 2002],
- absence of organizational learning and/or inadequate investment in training: this ties in with the previous element *i.e.* (adequate) training implies funding and time taken away from working time [Loo 2002].

This study investigates efficient practices in decision-making to reduce the lengthy delays in decisions. In this thesis, "efficient" is chosen to qualify practices as ways of performing an activity that help achieve results qualitatively and quantitatively, preventing waste of energy, time, or cost, according to circumstances, taking into account human well-being. Results can be in terms of conception, production, delivery, or decision milestones (wherein a decision is expected). In the next chapter, a methodology is proposed and used to identify and structure: 1) the causes of delays in decision-making in drug development projects, and 2) efficient practices that help make decisions more effectively and quickly, taking into account human and contextual factors.

7

Collecting and structuring method

There is no such thing as a logical method of having new ideas... every discovery contains an "irrational element", or "a creative intuition".
Karl Popper

In this chapter, our method to investigate the problem of delay in collaborative decision-making under uncertainty is presented. This method is based on interviews with the actors who contribute to decision-making. It aims to identify and structure the causes of delay and the efficient practices that help reduce this delay. In section 7.1, first, the choice of cross-case study *versus* case study is explained. Secondly, we describe the design and validation of an interview grid and a pre-test. The profiles of the target actors are defined and the method for conducting interviews is explained. In section 7.2, a plan is proposed for the analysis of the content of the interview results.

7.1 Collection method

7.1.1 Approach to identifying and collecting causes of delay and efficient practices

A main source of the information about the causes of delay is provided by actors who have been involved for several years in decision-making and have worked in more than one company, or have experience of several management styles, in different periods, in the same company. An interview-based approach is appropriate to study and analyze the processes and organizational modes of individuals, revealing [Blanchet+ 2010]:

– a specific pathology,
– mode of performing a professional task.

An interview-based approach is taken to collect actors' feedback, and to cross-reference and analyze their opinions and recommendations on delays in the decision-making process. In this regard, the actors are interviewed and asked to think about their *good* / *bad* experiences, regarding the factors involved in delays.

Fig. 7.1 shows the different steps of our method of collecting and structuring causes of delay and efficient practices. It is presented in the form of a process made by

Table 7.1: Case study versus cross-case analysis, some elements come from Stokes 2007

	Case study	Cross-case analysis
Appropriation	preventing an infrequent but significant problem or reproducing a successful experience	resolving a frequent problem through the recurrent factors that affect it, in similar situations
Potential motivation	providing feedback on one experience because of its negative / positive particularity	capitalizing the multiple experiences to improve performance
Scope of study	deep on one experience of the actors of the same company	broad on several experiences of the actors from different companies
Type of information	detailed on one experience in a specific context	general on several experiences in various contexts
Source of information	concentrated in one company	dispersed in different companies
Type of analysis	simple	comparative
Potential results in the case of our study	causes of delay and efficient practices specific to one experience	recurrent causes of delay and efficient practices in multiple experiences

Signavio®. This process begins when the decision-making process is modeled (see section 5.3 on page 74).

The first step is to define what should be examined in order to study the problem of delay (step 1, fig. 7.1). Cross-case analysis and case-study are two possible choices to delimit a study[1].

Case study

A (single) case is an example of a phenomenon and a case study is defined as "an intensive, holistic description and analysis of a bounded system such as a single instance, phenomenon, or social unit" [Merriam 1988].

Cross-case analysis

Cross-case analysis is "an analysis that involves an examination of more than one case" and looks "for patterns appearing across several observations that typically represent different cases" [Babbie 2010]. Cross-case analysis consists in "grouping together answers from different people to common questions, or analyzing different perspectives on central issues" [Patton 2001].

Comparaison

Tab. 7.1 shows the differences between cross-case analysis and case-study. Cross-case analysis is appropriate to resolve a frequent problem by identification of the recurrent factors that cause it or could prevent it. Case study is appropriate to study an infrequent but significant problem such as an accident in order to prevent it or to study a successful experience in order to reproduce it. Performance will be improved in the two cases. The scope of cross-case analysis is broad and can include several experiences in the same company or in different companies. Case study is

[1] According to Stake+ 2000, "case study is not a methodological choice but a choice of what is to be studied." Some authors considered case study as a "method" *e.g.* Yin 2002.

deeper, but limited to one experience. Information collected in cross-case analysis is often general and multi-sources; while in a case study, information is detailed and concentrated.

Our choice

To study the recurrent problem of delay which repeatedly occurs in a specific type of decision, cross-case analysis is more adequate than case study (useful in its own right). Cross-case analysis allows the knowledge[2] of the actors, in relation to decision-making processes in several experiences, to be capitalized; while case study does not allow the recurrent causes of delay in decision-making to be identified and examined.

7.1.2 Choice of the type of questions

Multiple-choice questions and descriptive questions are two possibilities for an interview grid. The first involves a quantitative interview and the second a qualitative interview. Tab. 7.2 compares these two types of questions.

Multiple-choice questions in quantitative interviews

"Multiple-choice questions consist of a stem (*i.e.* a question or statement) and a series of options or alternatives" [Blanche+ 2008]. Multiple-choice questions are particularly relevant to quantify the "major issues surrounding" of a research topic [Grossnickle+ 2000] and implies these issues are known. A fixed range of answers are proposed in quantitative interviews [Bryman 2001], with multiple-choice questions. One advantage of multiple-choice questions is that they are rapid to answer and more actors will agree to answer them. It also makes statistical analysis possible. One disadvantage is that interviewees might be influenced by the proposed choices.

Descriptive questions in qualitative interviews

Descriptive questions are "general requests for information" about the experiences and beliefs of interviewees regarding a research topic [adapted from Allen Portsche 2008]. Descriptive questions are relevant when performing exploratory research [Grover+ 2006] *i.e.* when the factors that affect a phenomenon are not known. Descriptive questions are proposed in qualitative interviews, also called in-depth or intensive interviews [Adler+ 2010]. "An in-depth interview is a way of gaining information and understanding from individuals on a focused topic... the in-depth interview is a very particular kind of interaction, similar to a conversation" [Hesse Biber+ 2010]. In-depth interviews are potentially powerful to explore complex experiences [Longhurst 2009] and subjective and complex decision-making processes [Broom 2005]. One advantage of descriptive questions is that they avoid influencing interviewees. A second advantage is their utility in the study of new research topics. Descriptive questions and in-depth interviews make it possible to concentrate on each individual [Koenigsmann+ 2006]. One disadvantage of descriptive questions is the complexity of recording and analyzing in a large "survey" [Grover+ 2006; Koenigsmann+ 2006]. "Due to the large amount of information provided by each interview and the in-depth character of the analysis", a large number of interviewees is not practicable [Koenigsmann+ 2006].

Our choice

Thus, an in-depth interview style with descriptive questions was chosen for this study. It takes a lot of time, but reduces the possibility of influencing the interviewees and helps identifying some causes of delay and some efficient practices that might be ignored through a pre-defined multiple-choice questions.

[2] Here, knowledge of the actors means what they know about the way of doing their activities and not their scientific knowledge.

Table 7.2: Multiple-choice questions versus descriptive questions

	Multiple-choice questions	Descriptive questions
Appropriation	relevant to quantify the factors that affect a phenomenon [Grossnickle+ 2000]	relevant to identify the factors that affect a phenomenon
Size of sample	large	small [Koenigsmann+ 2006]
Type of interview	quantitative interviews	qualitative interviews also called in-depth or intensive interviews [Adler+ 2010]
Type of analysis	statistical analysis	qualitative analysis
Advantages	rapid to answer and also to analyze the results	avoid influencing interviewees by the choices proposed
Disadvantages	influencing interviewees	time-consuming to answer and also to analyze the results, complexity of analysis [Grover+ 2006; Koenigsmann+ 2006]

7.1.3 Design of the interview grid, its thematic axes and questions

After specifying the approach of the interviews, an interview grid should be constructed to help conduct the interviews (step 2, fig. 7.1).

The identification of the thematic axes and the construction of the interview grid are both determined by the research questions and hypotheses [Blanchet+ 2010]. In the study of delay in decision-making under uncertainty, interview questions should provide the opportunities for interviewees to explain their dis/comfort regarding current practices in decision-making and point out the causes of delay and efficient practices to reduce delay, related to:

Thematic axes of the interview grid

- **decision**, as the main subject of the interviews,
- **uncertainty** and the four main classes of the factors which create or affect uncertainty (see our definition of uncertainty presented in section 2.1.4 on page 29):
  - **object** class *i.e.* **information** about the projects on which the decisions are based,
  - **subject** class *i.e.* **human factors** regarding who prepares, makes, and executes the decisions, and the collaboration between actors,
  - **context** class *i.e.* **work environment** wherein the decisions are made,
  - **time** class *i.e.* **time to decide**.

The axes of the interview grid are: decision, uncertainty, information, human factors, and work environment. Each (human) decision is based on the information which might be uncertain, and is made by one or several actors in a context (not in a vacuum). Thus, these six axes are general enough to be considered in the study of a collaborative decision-making process when faced with uncertainty. According to which industrial sector is being studied, other axes may be added to the grid,

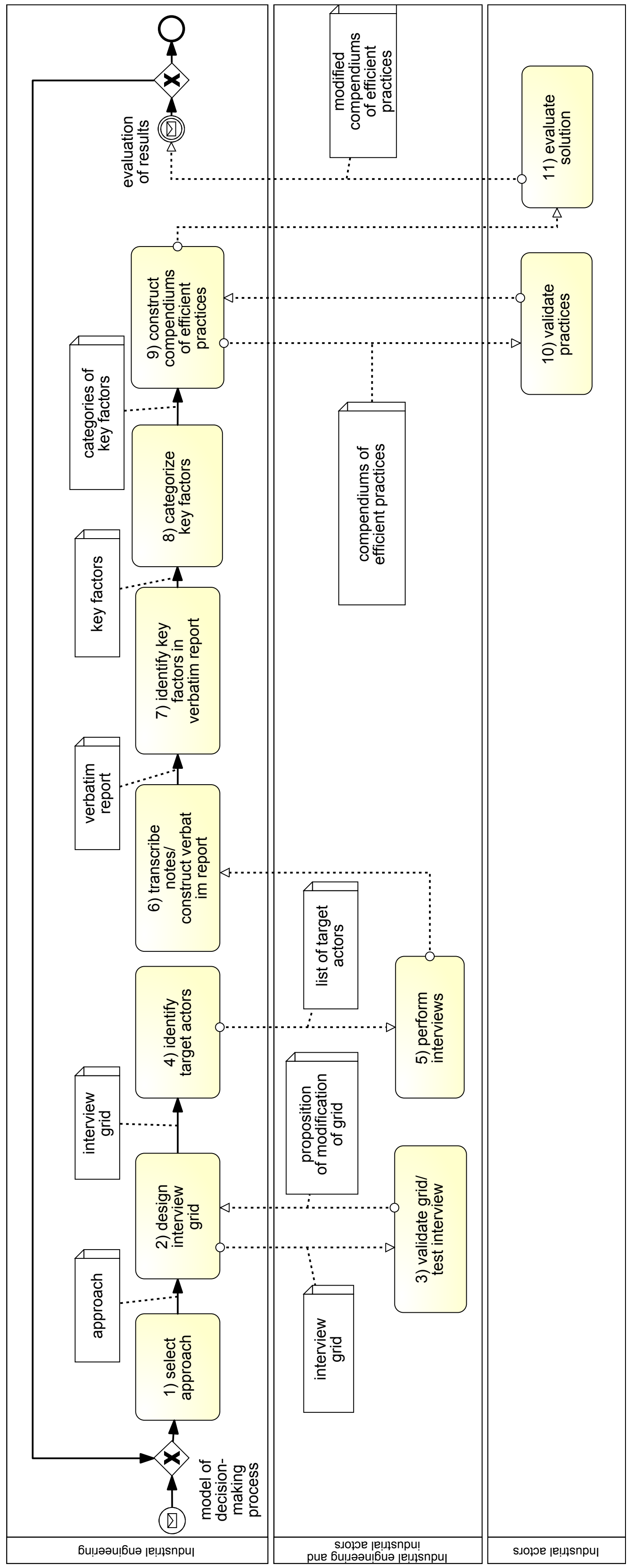


Figure 7.1: Steps of our method to investigate indecision problem through an interview-based approach, in BPMN with Signavio®

including other characteristics of the delayed decisions, specificities of the projects or the sector, and their impacts on delays.

The questions should be neutral enough to avoid influencing the interviewees in any particular direction. Each question should be on one, and only one, factor that affects decision. The first question of the grid can be about the opinion of interviewees on the effectiveness and rapidity of the decisions under study, to verify whether all actors agree that there is a problem in decision-making manifested by recurrent delay.

In each axis, the first question is about the most important aspect of the axis theme. In this way, the interviewees can begin to reply to the most important aspects, according to their own experiences. The last question is an open question that gives the interviewees the opportunity to add points that are not included in the questions. Between these two questions, the other questions should bring out different aspects of the axis theme: its impacts on the decision-making process, its role in delaying decisions, current practices, efficient practices, and the possible obstacles.

A pre-test interview

A pre-test with our industrial partner is performed in order to validate the interview grid (step 3, fig. 7.1). The clarity of the questions can be examined at this stage. Some improvements can be made, such as removing the ambiguities and adding some definitions or precision, using the words that industrial actors are acquainted with, and adding questions, if necessary. The test interview also gives an estimation of the required time that should be allocated for interviews.

7.1.4 Identification of target actors

Information life cycle as a key to identify target actors

The actors who are in charge of making decisions should be identified (step 3, fig. 7.1). Each decision is constrained and conditioned by information [Simon 1960; Pomerol+ 2008]. In a company, the actors who make *important strategical* decisions are not often those who provide information. One way to identify target actors is to examine their contribution in the information life cycle: from search / production, selection / filtering, transformation / aggregation, communication, until finally consumption / decision.

Why group the actors?

Identifying the points of convergence and divergence of different actors helps to understand the eventual difficulties encountered by each group of actors when seeking to improve their mutual understanding and collaboration. One purpose of these interviews is to verify whether the actors have the same perception of the problem of delay, its causes and solutions or whether their perceptions vary according to their different roles in the information life cycle or their various backgrounds and jobs.

Possible actor groupings

There are at least two ways to group the target actors: 1) the information life cycle, by which target actors can be identified, also offers the possibility of grouping them according to each stage in the life of the information, 2) different actors who contribute to the information life cycle can also be grouped according to their different jobs, such as: R&D actors, economists, marketeers, board of directors, etc. The choice of how actors are grouped depends on our knowledge of the problem of delay in decision-making in an industrial sector or an organization. If we do not have any information about the possible misunderstandings between actors, we can begin by the first grouping option and conduct interviews with the groups of actors who play important roles in the information life cycle. If, in the interview results, divergence points between different jobs emerge, the second grouping option may prove helpful to improve the collaboration between groups of actors with different jobs.

Samples of interviewees should preferably contains juniors, seniors, and retirees, since each population may have some advantages regarding the information that can be collected:

Asctors' age brackets

- interviewing a retiree is potentially valuable for three reasons: 1) a broad vision due to a wide experience that allows different aspects of a subject to be analyzed, 2) the benefit of hindsight that allows analysis of phenomena with less subjectivity and emotion, 3) freedom of speech, which allows openness in speaking, 4) being free of the usual time constraints of the people with a high degree of expertise,
- juniors have less experience but they may have a different and new perception of the problems and solutions,
- seniors are still involved in the decision-making process and often have important responsibilities and may provide interviewers with information on current experiences.

7.1.5 Conducting semi-directive interviews

The interviews are performed with the target actors (step 4, fig. 7.1). The objective is to collect the unspoken information related to the difficulties of decision-making and possible improvements.

The interviewees should feel free from their strict duty of confidentiality, so as to analyze the current practices candidly. One of the difficulties is to create an atmosphere of confidence for the industrial actors. Audio-video recording and note taking are two possibilities to collect information during interviews. Recording interviews allows the interviewer to concentrate on listening and observing interviewees during the interviews and facilitates a faithful transcription of the statements and the tones of the interviewees after the interviews. The main disadvantage of recording is that the interviewees may feel uncomfortable being recorded [Longhurst 2009], and this can adversely affect a candid and forthright dialogue. In this regard, three measures are taken in our study:

Gaining the confidence of interviewees

- taking notes instead of recording the interviewees to avoid harming their confidence,
- conducting the interviews outside of their companies,
- assuring the interviewees that the transcription of the interviews will be anonymized, eliminating the names of the companies, the actors and the molecules under discussion.

In order to take notes faithfully, more than one person should attend the interviews. One person (the principal interviewer) asks the questions and guides the interview. The other mainly take notes but can also ask questions.

The interviewees should feel comfortable about talking openly. So as not to interrupt or influence them and in order to collect the maximum amount of information, the in-depth interviews are semi-directive. In in-depth interviews, the interviewer begins an interactive *conservation*[3] by asking a question, but then says very little and remains an "active listener" encouraging interviewees to continue speaking [Hesse Biber+ 2010]. The questions are there to highlight some important factors that influence decisions, and encourage actors to give their feedback on these factors. As Bryman 2001 describes, the flexible style of the in-depth interviews allows an open dialogue that is not limited to the questions on the grid. Thus, in answering a question, an interviewee may spontaneously evoke some other factors that are related to the other questions or not taken into account in the grid. The interviewers can intervene, when:

Strategy of the intervention

- an interviewee points out a cause of delay, but does not give explanations concerning its mechanism and its eventual underlying causes,
- an interviewee proposes an efficient practice, but does not explain why it is efficient or does not specify whether during his career the proposed practice has been implemented in another company or in the same company in another period,
- an interviewee outlines a factor that affect decision-making, but his analysis is different from (even contradictory to) another impact analysis by another interviewee. In this case, the interviewer let the interviewee come to the end of his reasoning and then gives the different / contradictory points of view, in order to generate a debate and understand the differences.

In this way, as Adler+ 2010 describe in qualitative interviews, the interviewer adapts the interview to each interviewee.

All the interviewers take notes. After each interview, all the notes should be compared and merged. As Longhurst 2009 mentions, the transcription should be done after conducting the interview, when it is foremost in the minds of the interviewers.

Semi-directive interviews imply that the results are not as structured as the grid and thus, need to be reorganized. The analysis of the interview results is the subject of the next section.

7.2 Content analysis of the verbatim report

The full transcriptions of each interview by different interviewers are cross-referenced to the transcription made by the principal interviewer, in order to complete it (step 5, fig. 7.1). Thus, only the most complete transcription (meaning the transcription of the principal interviewer) is considered. The combination of the transcriptions of all interviews is constructed into a verbatim report.

In the verbatim report, all the names of companies, people, projects, services, products should be eliminated to respect the confidentiality of the interviews. In addition to names, all indications that may allow a company or a person to be recognized should also be eliminated. It should be noted that some indications

[3] Hesse Biber+ 2010 distinguish an in-depth interview from a "normal" conversation wherein there is more "back-and-forth interactions" and two people express their ideas.

might be revealing only to the experts in the field. Thus, identification of these indications should be assisted by an actor of the industrial field that is being studied.

We introduce here the notion of *key factor*, a term that will be used frequently in the rest of this document. According to the Oxford English Dictionary [4], a factor is "a circumstance, fact, or influence that contributes to a result." In our study, a key factor is a "thing" (a circumstance, a fact, an influence, an emotion, a relationship, etc.) that can affect decision-making.

The purpose of section 7.2.1 is to identify the key factors that in/directly affect decision-making and the purpose of section 7.2.2 is to classify the key factors in order to measure the importance of the impact of each class.

7.2.1 Identification and analysis of the key factors in decision-making

Based on the interview results, a verbatim report is established, including the exact expressions of the interviewees. The purpose of this step is, first, single out (in the verbatim report) the key factors that affect in/directly decision-making, their impacts, and their particular contexts (step 6, fig. 7.1). Then, the key factors, underlined by different interviewees, are cross-referenced and the repeated and controversial ones, in terms of impacts on decisions, are identified.

In the verbatim report, some statements contain the key factors outlined by the interviewees, and some other statements give more explanations about the key factors. These two types of statements are distinguished: 1) elementary statements which contain only a key factor, 2) secondary statements which explain the main idea of elementary statements. Each secondary statement focuses on one of these elements:

Typology of the secondary statements

1. an observation which is where an interviewee draws attention to the key factor, because of its perceived in/effectiveness.
2. the impacts of a key factor in terms of delay in decision-making,
3. the context wherein a key factor can impact on decision-making,
4. an illustrative example.

First, each elementary statement is grouped with its associated secondary statements. The first output of this step is a partition of the set of all statements into subsets which contain one and only one elementary statement (key factor) and potentially some secondary statements.

Secondly, the key factors repeated by the same interviewee (in the same way) are deleted.

Thirdly, the key factors repeated, exactly in the same way, by different interviewees are considered as the salient factors. A specific analysis is reserved for these salient factors, which is based on two degrees of frequency associated with each of them:

Two degrees of frequency for each salient factor

– **exact frequency index**: the number of the exact repetitions of a salient factor, meaning with the same words or synonymous terms,

[4] http://www.oxfordreference.com

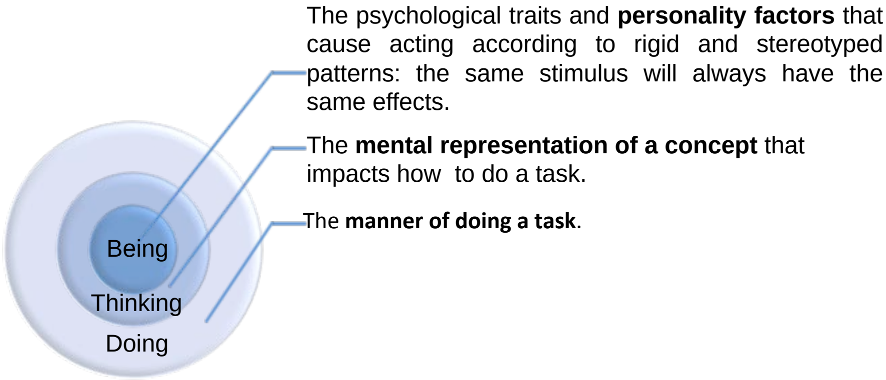


Figure 7.2: Three levels of the key factors

– **total frequency index**: the exact frequency index plus the number of key factors that are not exactly the same as the salient factor, but are related to the salient factor because they consider different aspects of the same theme, called the central theme.

The total frequency index shows the importance of a central theme, and the exact frequency index shows which aspect of a central theme affects decision-making most significantly.

Finally, the controversial factors are detected, meaning those that can have different or even contradictory impacts on the decision-making process, according to different interviewees. The different perceptions of the controversial factors can be analyzed according to the various actors interviewed who evoked them, or according to their contexts, etc.

The key factors identified through the verbatim report - those most cited and also the controversial ones - give information about the causes of delay and about efficient practices. But they do not determine the causes of delay and the efficient practices related to each activity, the actors who should implement efficient practices, and the areas to improve. Identified key factors should thus now be classified according to these elements. It helps provide each group of actor with a compendium of efficient practices that they should implement to perform their activities. It is the subject of the next section.

7.2.2 Categorization of the key factors in decision-making

Content analysis stands or falls by its categories... since the categories contain the substance of the investigation.
Berelson 1952

In content analysis, categorization is an operation to classify the elements of a set (into subsets, called categories), by differentiation and then grouping by analogy, according to predefined criteria[5] [Bardin 1997], where a criterion is a condition by

[5] « La catégorisation est une opération de classification d'éléments constitutifs d'un ensemble par différentiation puis regroupement par genre (analogie) d'après des critères préalablement définis » [Bardin 1997].

which an element is judged to belong to a subset[6]. A criterion may be semantic, synthetic, lexical, expressive, etc. [Bardin 1997].

In the case of our study, categorization is performed on the set of the identified key factors, noted F. Categorization partitions F into categories of the key factors that share common properties[7] [adapted from Bardin 1997]. Categories are determined by the semantic criteria *e.g.* the category of all the key factors that concern a given activity (step 7, fig. 7.1).

A "correct" categorization should also satisfy five conditions according to Bardin 1997:

Conditions of a "correct" categorization

1. mutual exclusivity: in each point of view of the content analysis, each key factor must belong to one and only one category. The definitions of the categories and the criterion of the membership should clearly be defined,
2. homogeneity: the exclusivity condition depends on the homogeneity of the categories. The operation of the categorization is the same for the all key factors,
3. pertinence: categories should reflect the research intentions and analysis,
4. objectivity and fidelity: a very important condition that can be supported by the previous ones,
5. productivity: this pragmatic condition implies that the definitions of the categories help the new research hypotheses emerge.

Identification of the relevant categories

"The categories chosen must reflect and be sensitive to the research problem" [Longhurst+ 2008]. Thus, research hypotheses and questions lead to the identification and definition of relevant categories. In the case of our study, the research questions are as follows. What are the causes of delay related to each activity? For a given activity, what are the efficient practices that need to be implemented in order to reduce delay in decision-making? Who are the actors involved in the causes of delay? What are the efficient practices destined towards each group of actors? etc. The answers to these questions will divide the set of the key factors (F) into categories. For example, the last question partitions F into categories where each of them includes only the practices destined towards one group of actors. Thus, to answer this question, we have as many categories as there are groups of actors. In this way, research questions offer different points of view to categorize the key factors. A point of view of categorization is defined as a particular "way of considering"[8] that orients categorization so as to answer a question. In the next lines, we formalize the operation of categorization according to different points of view.

Formalization of the categories of each point of view

The set of all points of view is noted Π. The point of view number i is noted Π_i, where $1 \le i \le I$ and $I = |\Pi|$. The key factor number l is noted f_l, where $1 \le l \le n$, and $n = |F|$. The category number j of the point of view number i is noted K_{ij}, where $1 \le j \le J$ and $J = |\Pi_i|$. Six points of view are proposed to answer six questions by categorizing the key factors:

[6] Adapted from the definition of criterion by the Oxford English Dictionary: a principle or standard by which something may be judged or decided, available in http://www.oxfordreference.com

[7] « Les catégories sont des rubriques ou classes qui rassemblent un groupe d'éléments (unités d'enregistrement dans le cas de l'analyse de contenu) sous un titre générique, rassemblement effectué en raison des caractères communs de ces éléments. » [Bardin 1997].

[8] Adapted from the definition of point of view by the Oxford English Dictionary: a particular attitude or way of considering a matter, available in http://www.oxfordreference.com

1. is the factor a cause of delay in decision-making or an efficient practice to reduce it?
   Formulation point of view: Π_1= {*Cause, Practice*}:
   - K_{11}=*Cause*= {key factors that are cited as the causes of delay},
   - K_{12}=*Practice*= {key factors that are cited as the efficient practices to reduce delay},
   - criterion: this depends on the formulation of the elementary statement that contains the key factor,
2. is the key factor related to a way of doing, thinking, or being?
   Level point of view: Π_2= {*Doing, Thinking, Being*}:
   - K_{21}=*Doing*= {key factors concerning a manner of doing an activity},
     Doing is the manner to carry out an activity,
   - K_{22}=*Thinking*= {key factors concerning a manner of thinking},
     Thinking concerns mental representations that are flexible and can be modified,
   - K_{23}=*Being*= {key factors concerning a manner of being},
     Being is the essence, the most important properties of people that make them who they are and how they act, according to rigid patterns that are difficult to change[9],
   - criterion: this depends on the semantics of the key factor[10](see fig. 7.2),
3. is the key factor related to the object, subject, or context?
   Sector point of view: Π_3= {*Object, Subject, Context*}:
   - K_{31}=*Object*= {key factors concerning information processing about the project},
   - K_{32}=*Subject*= {key factors concerning the actors and their interactions},
   - K_{33}=*Context*= {key factors concerning internal and external environment of an organization},
   - criterion: these categories, which take root in our definition of uncertainty (see section 2.1.4 on page 29) and the typology of uncertainty factors (see fig. 2.4 on page 30), helps determine the sector of a key factor from this point of view,
4. which activities of the process are concerned by the key factor?
   Process point of view: $\Pi_4 = \{Activity_1, ..., Activity_t, ..., Activity_T\}$, where T is the number of the activities in the model of the decision-making process[11] that are mentioned by the interviewees, called critical activities. A first reading of

[9]Subjective values are strongly involved in this level.

[10]We identify these three levels through the reading of the verbatim report. The interviewees implicitly distinguish these levels in the formulation and semantics of their statements, when they analyze each other's practices: "they **do**..., they **think**..., they **are**...". We noticed, *a posteriori*, that these levels are considered in philosophical and religious texts: "Good thoughts, good words, good deeds" in Zoroastrian ethics [Clark 1998], "Be, think, do what feels right" in Buddhism [Hansard 2011], "...a perfect standard which prescribes being, thinking, doing..." in Christianity [Carroll 1980], "...a historical investigation into the events that have led us to constitute ourselves and to recognize ourselves as subjects of what we are doing, thinking, saying" in Foucault's philosophy [Foucault+ 1984].

[11]This can be provided following the method explained in chapter 4 on page 63, as is presented in fig. 5.7 on page 88 for Go / No Go decision-making process.

the interview report is necessary to determine the activities pointed out by the interviewees to construct Π_4.

- K_{4t} = Activity number t = {key factors that concern activity number t of the model},
- criterion: the activity of the model, in which a cause of delay is identified or an efficient practice should be implemented,

5. which group of interviewees underline the key factor?
Interviewees' point of view: $\Pi_5 = \{Group_1, ..., Group_g, ..., Group_G\}$, where G is the number of the groups of interviewees, depending on their roles in the decision-making process:
   - K_{5g} = group number g of interviewee who identified the key factor,
   - criterion: the role of the interviewee in the decision-making process, determined in section 7.1.4 on page 120,
6. who is the actor (or group of actors) that should consider the key factor in implementing the critical activities?
Actors' point of view: $\Pi_6 = \{Actor_1, ..., Actor_a, ..., Actor_A\}$, where A is the number of the actor (or group of actors) involved in the causes and practices mentioned by the interviewees. A first reading of the interview report is necessary to establish the list of actors:
   - K_{6a} = actor (or group of actors) number a who is involved in a cause of delay or should implement an efficient practice,
   - criterion: actors mentioned by the interviewees, regarding their positions in the Resource Breakdown Structure (RBS)[12] of the enterprise.

The categories of the first three points of view do not depend on the application case. The categories of the last three do depend on the application case, its model of the decision-making process, and the actors who contribute to the process. Additionally, a first reading of the verbatim report is necessary to identify the potentially relevant categories which are not taken into account in the primary hypotheses [Blanchet+ 2010].

Each key factor is annotated by a sextuplet of the categories to which it belongs. The annotation function, noted a, is defined as follows:

$$a : F \rightarrow \Pi, \quad a(f_l) = [\boldsymbol{K_{ij}}] \tag{7.1}$$

where $\forall f_l, \Pi_i, \exists! K_{ij} \in \Pi_i$ such that f_l is annotated by K_{ij}.

From each point of view, the categories are mutually exclusive and they cover all the factors, meaning that they give a partition of the verbatim report.

Other categories can be added, according to the characteristics of the indecision problem. They should satisfy the mentioned conditions for a "correct" categorization. After that, the categories constitute a stable analysis grid that should help to decompose the information as much as possible, as should be the case in the interview grid [Blanchet+ 2010]. In this way, categorization of the key factors that affect decision-making helps cross analysis, for example:

[12] "A hierarchical structure of resources by resource category and resource type used in resource leveling schedules and to develop resource-limited schedules, and which may be used to identify and analyze project human resource assignments" [PMI 2008].

- **causes / practices versus activities**: the causes of delay and efficient practices related to each activity,
- **causes / practices versus group of actors**: the efficient practices that should be implemented by each group of actors (step 8, fig. 7.1),
- **group of actors versus object / subject / context**: the similarities and differences between opinions of different groups of actors,
- **causes / practices versus object / subject / context**: the area to improve, namely factors relating to the object *e.g.* information research, factors relating to the subjects *e.g.* mutual expectations, and factors relating to the context *e.g.* culture of enterprise.

These elements help each actor to step back from his role in the decision-making process, being conscious of the perceptions and expectations of the other actors.

Finally, the causes outlined and the practices recommended should be validated by the actors (step 9, 10, fig. 7.1).

8

Application to problem of delay in difficult Go / No Go decisions

Indecision is often worse than wrong action.
Henry Ford

In this chapter, the methodology outlined in chapter 7 on page 115 is applied to the indecision problem in drug development projects. This application is accompanied and assisted by our industrial partner.

In section 7.1.1 on page 115, we explained the reasons for choosing cross-case analysis in order to study a recurrent problem of delay in decision-making in an organization or in an industrial sector. In addition to these general reasons, some specific reasons reinforce this choice in the case of our field of study:

- the length of a doctoral thesis does not allow a case study on one drug development project to be performed since such projects last on average more than 13 years [Paul+ 2010] and their consequences might only be known over the long term,
- as explained in section 1.2.2 on page 16, the problem of delay occurs in difficult Go / No Go decisions, of which two or three are made during the life of a project. Therefore, observation of only one project may not be sufficiently rich when compared to feedback from experienced actors on several delayed - and also on time and effective - decisions.

8.1 Designing and conducting interviews

The axes and the questions of the interview grid and the profiles of the target actors are described in this section.

8.1.1 Six thematic axes of the interview grid

An interview grid is constructed to collect information about the causes of delay, the current practices of the actors in the decision-making process, and the efficient practices recommended by the actors.

Six thematic axes are proposed in section 7.1.2 on page 117 to construct an interview grid in order to investigate the problem of delay in collaborative decision-making under uncertainty: decision, uncertainty, information, human factors, work environment, and time. In this way, our interview grid includes 35 direct questions and 6 open-questions, in six axes (see the axes of the grid in fig. 8.1):

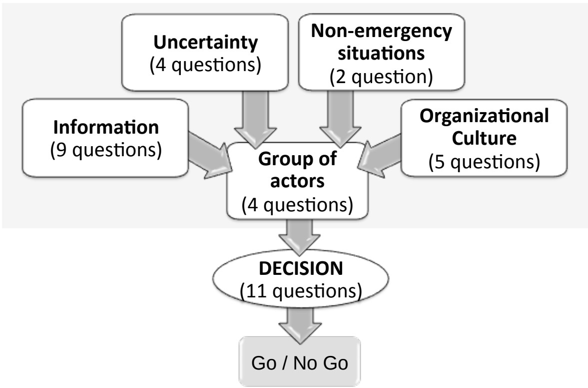


Figure 8.1: Thematic axes of the interview grid

Thematic axes of the interview grid

– **decision**: the main topic of the interviews is decision. Eleven questions are asked about the postponement, invalidation, and difficulties of Go / No Go decisions, storage of the history of making/delaying these decisions, and the factors that stimulate decision-makers to finally make a decision that has been lengthily delayed (see appendix B.1 on page 177),

– **uncertainty**: despite a large number of tests on the molecule, the degree of uncertainty remains high. Four questions are asked about the frequency of uncertainty, its sources, its impact on decisions and the way uncertainty is dealt with (see appendix B.2 on page 177). More questions in each class of factors of uncertainty are also asked:

  – **object** class *i.e.* **information**: Go / No Go decisions are based on information about the properties of the potential new medicine. Information has an important role in shaping Go / No Go decisions. Nine questions are asked about the importance of presentation of information by project managers to decision-makers, its quality, quantity, objectivity, and accessibility for the decision-makers in various fields (see appendix B.3 on page 177),

  – **subject** class *i.e.* **human factors**: Go / No Go decisions are collaborative, which implies taking into account collaborative factors in human relationships. Four questions are asked about the influences of the group on individuals and *vice versa* (see appendix B.4 on page 178),

  – **context** class *i.e.* **culture of the enterprise**: the characteristics and culture of enterprises have an important impact on the ways decisions are taken. Five questions are asked about the type of governance, structure and functioning of decisional system, flow of information, and other implicit and explicit rules (see appendix B.5 on page 178),

  – **time** class *i.e.* **non-emergency of situations**: Go / No Go decisions with long-term consequences are often considered non-emergency. Two questions are asked about the impact of the non-emergency of decisions (see appendix B.6 on page 178).

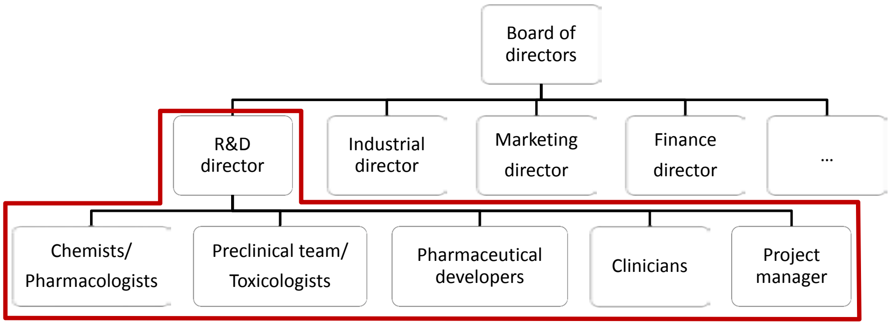


Figure 8.2: General R&D actors in composition of steering committees

The questions of the grid have been validated by our industrial partner who helped to reformulate some questions in order to make them clearer, using the keywords of the field such as benefit-risk balance, decision recycling, and jargon translator. In the axis of information some questions on the quality and time of the presentation of information are added.

8.1.2 Decision-makers and project managers as target actors

The model of the Go / No Go decision-making process, provided in fig. 5.2 on page 81, shows the contribution of actors to the information life cycle. In the last stage, difficult Go / No Go decisions are often delayed. The actors who play two main roles in the last stage of the model are: 1) decision-makers (members of steering committee) who make decisions about projects and have to be convinced of the value of projects, 2) project managers who present the projects and provide the first group with the information they need to decide. These roles determine the choice of the target actors: decision-makers and project managers.

In this study, a small sample size was intended because of:

- the rarity of difficult Go / No Go decisions, since a project portfolio rarely contains more than 10 projects and there are only 2 or 3 difficult Go / No Go decisions during the life of a project[1],
- the rarity of decision-makers and project managers who are the actors with a high level of expertise and are few in number,
- the sensitivity of the subject (public health),
- a high degree of confidentiality in R&D projects in general and in the pharmaceutical sector particularly,
- the nature of our questions (pathological study of decision-making) that implies criticizing oneself, colleagues, companies, and even banks and politicians,

[1] It should be noted that difficult Go / No Go decisions are not frequent but they are frequently delayed. They often concern innovative projects that, in the case of success, develop an effective and safe medicine for patients and a profitable product for companies. Thus, it is important to make these decisions quickly and effectively for both public health and the pharmaceutical industry.

Table 8.1: Profiles of the seven interviewees and the length of the interviews

Number of interviewee	Sex	Age	Last role of interviewee (PM/DM)	Expertise	Experience related to decision (years)	Number of employees of last company	Length of interview (hours)
1	F	40	PM	Toxicology	10	2,000	4h
2	M	40	PM	Management	10	2,000	2h
3	F	30	PM	Management	4	10,000	2h
4	M	45	DM	Chemistry	15	6,000	4h
5	M	65	DM	Pharmaceutical development	18	10,000	8h
6	M	65	DM	Clinical studies	20	23,000	3h
7	M	61	DM	Pharmaceutical development	25	2,000	3h

- the form of the questions (open, neutral and descriptive ones) that are more difficult to answer compared to multiple-choice questions,
- the number of the questions (35) that are time-consuming to answer.

Seven actors of the pharmaceutical industry agreed to give an interview. These actors can be grouped according to their last roles in the decision-making process: 3 project managers, 4 decision-makers. Decision-makers have more experiences and three of them were project managers before becoming decision-makers.

This sample covers the main R&D actors in the steering committee (see fig. 8.2): chemists / pharmacologists, toxicologists / pre-clinical experts, pharmaceutical developers, clinicians, and also project managers. The interviewees are 2 juniors, 3 seniors, and 2 retirees.

Most of the interviewees have worked in more than one company during their career. These are the companies with more than 50 subsidiaries and usually with export sales that represents around 80% of their total turnover.

8.1.3 Conducting interviews

Seven interviews were performed during the summer and fall of 2011. The interviews were semi-directive and lasted at least two hours, at most eight hours (on two occasions), with an average duration of 3:40 hours. At least two and sometimes three people took notes during the interviews. Then, the notes were cross-referenced in order to reduce the subjectivity of the interviewers and to provide a faithful transcription of the interviews. Some interviewees were solicited by email to expand upon their opinions and some of them spontaneously contacted us to add other reflections or the points of view of their colleagues.

8.2 Interview analysis

A verbatim report was constructed from the combination of the full transcription of each interview, made by the principal interviewer and completed with the transcriptions of two other interviewers. The verbatim report comprised 18,200 words.

As explained in section 7.2, the verbatim report was anonymized. Additionally, all indications that could have helped identify a company or a person were eliminated. This was done in collaboration with our industrial partner who, through multiple collaborations with different companies, knows the specificities of each company and the elements that may reveal a confidential name to the actors of the pharmaceutical industry.

In this section, first, the key factors are outlined in the verbatim report. Then they are classified into categories, according to the properties shared.

8.2.1 Identification and analysis of the key factors in Go / No Go decisions

All the interviewees agree that Go / No Go decisions are frequently delayed in drug development projects. Each interviewee, according to his functional role and feedback, identifies some key factors that affect the decision-making process.

The objective of this section is to identify and analyze the key factors that affect the Go / No Go decision-making process, the salient factors that are pointed out exactly in the same way, the related factors that consider different aspects of a same central theme, and the controversial factors with different impacts on decisions.

In the verbatim report, 362 key factors (elementary statements) are identified, 22 of them (6%) are repeated by the same interviewees (in exactly the same way) and are deleted and are not the subject of any analysis. From 340 which remain, 197 factors are mentioned only once (exact frequency index=1) and 55 factors are repeated a total of 88 times (in exactly the same way) by different interviewees, with 2 ≤ exact frequency index ≤ 4. These are the salient factors which are the subject of a particular analysis. The number of the key factors, without the repetition of the salient factors, is 252. The percentages announced hereafter in our analysis are based on these 252 factors (see fig. 8.4). Two examples of key factors are given.

"Fear of uncertainty", is evidenced from this elementary statement: “Uncertainty of biology scared decision-makers” and its secondary statements are as follows:

1. observation: “inability to act under uncertainty”,
2. impacts: “deferring decisions, expecting information that may reduce uncertainty”,
3. context: “particularly in the companies with several decision-makers who are afraid of uncertainty”,
4. example: “someone who comes from another industry, the car industry for example, has difficulty in decision-making faced with the high degree of uncertainty in biology.”

"Affective attachment to projects" is evidenced by the following elementary statement: “A project is difficult to stop, a project is like a baby”:

1. observation: “difficulty of making, accepting, and executing No Go decisions”,
2. impacts: “deferring No Go decisions”, “trying to change No Go decisions”,
3. context: “particularly in the companies with a low throughput in the pipeline”,
4. example: “the actors wept, after a No Go decision.”

8.2.2 Salient factors in Go / No Go decision-making process

Tab. 8.2 shows the first salient factors with their exact and total frequency indexes. The last column shows the group of actors who underlined the key factor: Project Managers (PM), and Decision-Makers (DM).

Table 8.2: Salient factors sorted by total frequency

Salient factors	**Exact Frequency**	**Total Frequency**	**Pointed out by (Group of actor)**
Fear of uncertainty	4	22	PM & DM
Fear of hierarchy	4	15	PM & DM
Difficulty of No Go decisions	3	14	PM & DM
Taking into account belief/conviction-sharing process	4	11	DM
Sending the results to decision-makers	4	10	PM & DM
Lack of complete interpretation of the results	1	10	PM & DM
Information overload in decision meetings	1	9	DM
Short and ill-organized debate	3	7	PM & DM
Difficulties caused by jargon	3	6	PM & DM
Analyzing risks	3	5	PM & DM
Collecting comments by round table discussion	3	5	PM & DM
Applying a template for presenting the results	4	4	PM & DM
Sending the agenda of the meeting	4	4	PM & DM
Lack of communication of the decisions made	4	4	PM & DM
Taking necessary time in shaping decisions	3	4	PM & DM
Wearing effect of the steering committee	3	3	DM
Redefining the decision-making process	3	3	PM & DM

8.2.2.1 Fear of uncertainty related to biology

Fear of uncertainty is repeated exactly in the same way 4 times. Thus, its exact frequency index is 4. The central theme of this salient factor is "uncertainty" which is repeated 18 times in other key factors, developing its different aspects, such as:

- perception: the interviewees consider that uncertainty is mainly perceived negatively by their colleagues, especially those who are unfamiliar with uncertainty: “For some actors, working with uncertainty is like being on a rudderless ship”, as one interviewee puts it. For some actors, it is confused with risk; they call for a quantitative evaluation of uncertainty. However, uncertainty is inherent in decision-making, especially in innovation. The positive aspects of uncertainty are ignored. For example, it is a source of challenge, opportunity, and innovation and gives actors a degree of freedom in their actions.
- evaluation and treatment: to process uncertainty, the interviewees propose a primary qualitative evaluation of uncertainty that can progressively becomes quantitative, up-to-date evaluation of uncertainty, dilution of uncertainty by developing the back up and follow up molecules (a tree of similar molecules), and belief-sharing to combat fear of uncertainty.

The total frequency index of "Fear of uncertainty" is 22, which is the total number of the key factors with "uncertainty" as the central theme.

8.2.2.2 Fear of hierarchy

Fear of hierarchy is also exactly repeated 4 times. Its different aspects are mentioned 11 other times in different key factors. According to the interviewees, fear of hierarchy is problematic at two levels:

- for project managers: who do not give a clear interpretation of the raw results, since a *bad* result can be considered by their superiors as "a lack of sufficient effort", as one interviewee affirms. It is particularly problematical in a multidisciplinary field such as the pharmaceutical sector wherein a project manager is considered as a "jargon translator". Consequently, decision-makers are not provided with adapted interpretations of the results to make decisions.
- for decision-makers: who do not express themselves in the presence of their superiors at all or at least not before knowing what their bosses think about a project. Consequently, unofficial corridor discussions become richer than official ones during the meetings. Therefore, the composition of the steering committee, meaning the existence of different levels of hierarchy in the steering committee, has a direct impact on the way and order in which decision-makers talk.

Fear of hierarchy harms the "team psychological safety" defined by Edmondson 1999 as “a shared belief that the team is safe for interpersonal risk-taking”; a safe team climate is characterized by interpersonal trust and mutual respect wherein team members are comfortable being themselves, asking a question, pointing out a mistake, or proposing an idea, without being embarrassed or punished.

8.2.2.3 *Difficulty of No Go decisions*

Difficulty of No Go decisions[2] is mentioned by the interviewees. Explaining a No Go decision relating to a lack of safety is always *easy* and rapid. However, it is difficult to make a No Go decision relating to a potential lack of competitiveness, regarding the existing medicines on the market. In these cases, the interviewees explained:

– the degree of this difficulty: “a project is like a baby”, “stopping a project is perceived as a tragedy”, “everything breaks down, everything collapses, like a shipwreck”, “a particular difficulty for the project manager”.
– the reasons for this difficulty: affective attachment *i.e.* considering the project as "human", stopping a project can be considered as a lack of effort, it is considered as interest-free, past costs of the project, low flow of the pipeline, list of the projects for the banks.
– the solutions to manage the end of the life of the projects that are going to fail:
  – to develop a tree of back-up and follow-up (similar) molecules instead of only an opportunist R&D strategy. In this way, a "dead project can be reborn in a more competitive form, in another therapeutic indication" on which human resource can be mobilized.
  – to prepare the actors for a No Go decision, avoiding the surprise effect. To give the actors a programmed time to digest a No Go decision.

Royer 2003 explains that a deeply held conviction is needed to get a project up and running, but “as the project moves forward, faith can blind you to increasingly negative feedback”. She proposes putting in place well-defined review processes to evaluate projects, questioning prevailing beliefs, demanding hard data on the viability of the projects, and “if necessary, forcefully making the case that it should be killed.” Royer 2003 draws attention to the fact that the role of the "project champion" is well studied, while the role of the "exit champion", who is able to kill projects before they become "money sinks", is not appreciated.

8.2.2.4 *Taking into account belief/conviction-sharing process*

This key factor is exactly repeated 4 times. Its central theme, "sharing conviction" is mentioned in 5 other key factors, underling its importance in vanquishing the fear of uncertainty and in shaping a decision as well as its mechanism which is compared to a "viral propagation". Belief/conviction-sharing should be taken into account by:

– project managers in presenting results: project managers present the results of the tests to decision-makers who do not know the detail of the project and whose opinions are shaped by the way results are presented. Decision-makers cannot be convinced by a project manager who is not convinced himself, or who does not communicate and share his conviction by using convincing sentences, appropriate wording, and also non-verbal communication such as eye movements, head movements, facial expressions, gesture, posture, sounds, proximity, and distance [Croucher 2004],

[2] As explained in section 1.2.2 on page 16, this thesis focuses on Go / No Go decisions which are difficult to make, meaning when the results are neither very *good* nor very *bad*. The results show that, in these difficult Go / No Go decisions, the No Go ones are more difficult to make.

– decision-makers between themselves in debate and discussion.

Interestingly, belief-sharing is mentioned a total of 9 times, by all decision-makers but by none of the project managers. This shows that project managers are not aware of the importance of the belief-sharing process for their interlocutors, namely decision-makers[3].

Charan 2001 underlines three reasons why people "speak their lines woodenly and without conviction": 1) they are intimidated by the group dynamics of hierarchy, 2) they are constrained by formality, 3) lack of trust. In a collegial structure, by definition, hierarchy and formality are trivial and relationships are often based on trust. Thus, people share their convictions more easily, compared to a formal structure wherein sharing conviction is less *natural* and requires an effort in terms of communication.

8.2.2.5 Sending the results to decision-makers

Sending results is mentioned by both project managers and decision-makers. The objective is to give decision-makers enough time to prepare the decision meeting. The problem is that some senior managers and decision-makers expect to receive the results of the studies the day after the tests have finished. "The preparation and presentation of the results is not considered as a real activity and the necessary time and resources are underestimated and not allocated to it", as one decision-maker affirms. Project teams and especially functional managers should participate in preparing the presentation of the results, according to another decision-maker. But one project manager considers that even if the presentation is sent to the decision-makers, some of them do not read it[4]. Project managers expect to be helped by the decision-makers who read the presentation, ask questions when they do not understand something, and suggest improvements.

8.2.2.6 Lack of complete interpretation of the results

As Jarrosson 1994 indicates, "it is not raw information that is used in decision-making, but rather the meaning given to the information"[5]. In Go / No Go decisions, project managers give meaning to complex and multidisciplinary information that should be understandable for the various experts on the steering committee. Thus, complete interpretation of the results, meaning that information adapted to the steering committee is necessary to make informed decisions.

Lack of complete interpretation is underlined by both groups of actors. Different forms of subjectivity in the interpretation of the results is described by the decision-makers and the reasons for this subjectivity is explained by the project managers:

[3] It is often difficult for a lecturer to measure how convincing he is. Politicians are aware of the importance of sharing conviction in their speeches. They ask their consultants whether they sound convincing. In the case of pharmaceutical R&D projects, only decision-makers who listen to the presentations of the project managers can measure their credibility and their power to share their conviction.

[4] The fact that some decision-makers do not read the presentation of the results (sent by project mangers), is mentioned in only one company. We cite it but do not generalize it as a common cause of delay, as is the case for sending results.

[5] « Ce n'est pas l'information brute qui sert à décider mais plutôt le sens qu'a cette information » [Jarrosson 1994].

- forms of subjectivity:
  - do not always present a *bad* result,
  - give a *bad* result uninterpreted, in the form of raw data or using too much technical jargon, so that it is not understandable by all decision-makers,
  - give a *bad* interpreted result, but minimize its presentation on the slide, compared to *good* results,
  - give the contradictory results in different slides, without linking them,
- reasons of subjectivity:
  - a possible fear or a sense of guilt, since a *bad* result can be considered as a lack of effort,
  - it is "taboo" to talk about a *bad* result,
  - a *bad* result may lead the project to its end (tragedy of No Go decision),
  - a possible fear of displeasing or upsetting their colleagues or their superiors by announcing a *bad* result.

8.2.2.7 Information overload in decision meetings

Information overload is only mentioned by decision-makers. It occurs when the amount of available information for decision-makers is more than they are able to process during a decision meeting. It is often related to rapid changes of a great deal of information where relationships are difficult to discern [Tweedale+ 2008]. Selectivity of information helps decision-makers avoid confusion, misunderstanding, and consequently, the waste of time and human resources [Janis+ 1977]. Decision-makers complain about the abundance of information during the decision meetings caused by:

- project managers who:
  - mix information relevant to the quantity of work performed on the project and information relevant to Go / No Go decisions, in order to "show that they have worked hard", according to one decision-maker,
  - enjoy presenting results and "they have also the backup slides", according to another decision-maker,
- decision-makers who:
  - need detailed information because of their speciality such as cardiologists, immunologists, and biochemists,
  - want and enjoy showing their expertise in interpreting the raw data and ask the project manager to give raw data concerning their specialities,
- the chairman of the board who takes the meeting as an opportunity to be informed about the other projects.

The abundance of information is not taken into account by the project managers as the major producers of information for Go / No Go decisions. It is perceived by the consumer of this information, meaning decision-makers, who cannot find accurate decision-related information easily among a large amount of information presented or discussed in the meetings.

8.2.2.8 *Short and ill-organized debate*

Both project-managers and decision-makers agree that, after the presentation of the results, debate and discussion is short and ill-organized. But the reason for this is different according to each group of actors:

- project managers think that decision-makers tend to skip debate and discussion. They ask project managers to begin the presentation of the results by the conclusions and recommendations in order to avoid a real debate,
- decision-makers think that a lot of time is spent on the presentation of the results and consequently, they do not have enough time to debate.

Decision-makers add another point that concerns lack of deliberation as a "fulcrum" of a decision, before its determination. "Distinction between the process of deliberation, and the act of decision determination" is also cited in the health field, in the evaluation of "good" decision-making [Elwyn+ 2010].

8.2.2.9 *Difficulties caused by jargon*

The consequences of overusing jargon in the presentation of the results are:

- decreasing the attention and concentration of the decision-makers who have different areas of expertise,
- hiding the interpretation of a *bad* result, by using technical words.

Using too much technical wording is contrary to the role of a project manager, called a "jargon translator" in the pharmaceutical industry. One decision-maker proposes establishing cross languages between different fields that are involved in drug development projects to favor mutual understanding.

8.2.2.10 *Some other examples of salient factors*

Some other salient factors, presented in tab. 8.2, are explained in this section. Risk identification and analysis is recommended by the interviewees, taking into account human factors in risk perception. High risks increase hesitation in decision-making. “The problem is not risk evaluation. There are tools that evaluate risks. The problem is how to manage risks?”, according to one project manager.

One of the decision-makers should manage the meeting, asking opinions of the others in order to ensure that everyone can express his view.

Using a template for presenting the results is mentioned by both project managers and decision-makers. But project managers add that even when a template is chosen with the agreement of decision-makers, they feel that the project managers want to influence them by a predefined template.

Sending out the agenda of the meeting is important to recall the questions that should be answered and the decisions that should be made, and helps actors to prepare the decision meeting.

Lack of communication on decisions made is “very frustrating for the people who have worked on a project” as one project manager puts it. This factor is also mentioned by a decision-maker. Using an appropriate and clear formulation of a made decision, explaining and communicating it to project team, help in the execution of the decision.

Taking necessary time to shaping decisions may seem paradoxical, regarding the first statements of the all interviewees regarding the delay in decision-making. It reveals a lack of time management specific to the decision-making process. According to one retiree decision-maker, “a difficult collaborative decision is not triggered suddenly, it is shaped, matured, shared, and digested little by little” by decision-makers. The speed of this process depends on the sub-processes of the all decision-makers. If a decision is bluntly made, it risks to be unmade and remade several times and sometimes during several months. This lost time can be more than the necessary time to shaping a decision.

The wearing effect of the steering committee is only mentioned by the decision-makers. They consider that in some companies a ritual has been established: “in the same office, the same people take the same seats and play the same roles in the same play, with the same lighting. It is as if the play has already been written”, one decision-maker describes.

Redefining the decision-making process is proposed by both project managers and decision-makers. In order to redefine this process and enrich it with efficient practices, the key factors that affect decision-making should be analyzed and structured. In the next section, incoherent key factors are outlined in the verbatim report.

8.2.3 Controversial factors in Go / No Go decision-making process

Tab. 8.3 shows the controversial key factors (2% of the key factors). In this section, the controversial factors and their positive and negative aspects are identified, but selecting one or both of them depends on each organizational context.

8.2.3.1 Presentation format

Presentation format (*e.g.* PowerPoint®) is synthetic, practical, structuring, illustrative, and thus, suitable to present the results of the tests, according to one decision-maker. However, one project manager does not agree: in text format (*e.g.* Word®), the results can be presented in-depth, in contrast to the presentation format.

Some studies, carried out in the education and organizational fields, criticize the use of a presentation format: it induces a weak analysis, since the information is parcelled into bullet points [Gabriel 2008; Hill+ 2012].

In Go / No Go decisions, this divergence of points of view can be explained by the role of each group of actors. On the one hand, the project managers produce a great deal of information from the raw data that cannot be easily presented in a few slides and criticize the decision-makers for preferring "easy information". On the other hand, decision-makers cannot discuss all the results at the time of the meeting.

8.2.3.2 Formal and collegial decision structures

The impact of formal and collegial decision structures is also a subject of disagreement among the decision-makers. Decision-makers with an Anglo-Germanic culture recommend a formal structure; while those with a Latin background prefer a collegial one.

The effects of collegiality are also discussed in judicial decision-making by Edwards 2003 who affirms that in a collegial structure, judges "are willing to listen, persuade, and be persuaded, all in an atmosphere of civility and respect." In American presidential decisions, the formal structure is described as a hierarchical pyramid, with the president at its apex and the collegial structure is compared to a wheel: "the president at the hub with advisers at the end of the spokes, directly connected to the president, and, along the rim, to each other" [Howell+ 2009]. Collegiality is also studied in airplane crashes and the results show that collegial decision-making in cockpits reduces the number of accidents [Morel 2012].

Go / No Go decisions, contrary to the cockpit decisions studied, are non-urgent and involve a larger number of experts, compared to a pilot and co-pilots. Collegiality creates a safe working environment for individuals to express themselves, but when the group of decision-makers is not small and decisions are not urgent, one side effect of collegiality may be a cacophony of opinions. Collegiality also implies reciprocal confidence between decision-makers which is easier to reach in small groups.

8.2.3.3 Number of decision-makers

For some decision-makers, the number of members of the steering committee is not important in decision-making, as long as they know how to make decisions. But according to others, it is difficult to make a decision within a group of more than 5 or 8 people.

As Morel 2012 puts it, it is important that each decision-maker has the time to express himself, and this is usually difficult with a large number of decision-makers.

8.2.3.4 "Corridor" discussions

For some interviewees with a Latin background, the unofficial discussions (corridor discussions) about the results of the tests help shape and digest a decision. Some others with an Anglo-Germanic culture believe that discussions about the results or decisions must officially take place and be shared in a formal meeting. Corridor discussions imply confidence and collegiality between people who discuss difficult and sensitive topics in private. Corridor discussions are not problematic by themselves, if the actors participate in formal discussions as well as in informal ones. But it is a decisional pathology if the fear of hierarchy leads the actors to participate only in informal discussions outside of meetings.

Table 8.3: Controversial factors

Controversial factors	First point of view	Second point of view
Format of the results of the tests and studies	Presentation format is superficial. Text format is more appropriate.	Presentation format is synthetic, and structuring.
Type of collaborative decision	Formal decision-making is more appropriate.	Collegial decision is appropriate.
Number of decision-makers in the steering committee	A limit is needed.	The number of decision-makers is not an important factor.
Corridor discussions	Limiting corridor discussions about results and decisions.	Corridor discussions help shaping and maturing decisions.
Management of non-emergency situations	To consider non-emergency situations as emergency.	Not to consider non-emergency situations as emergency ones.

8.2.3.5 Managing non-emergency situations

Non-emergency is considered as "a brake on decision-making". All the interviewees confirm this fact. The concept of non-emergency in Go / No Go decisions recalls the concept of "hidden emergency"[6] introduced by Lenfle+ 2004 in innovative projects wherein the superposition of the various design processes makes projects' milestones less visible. In drug development projects, as explained in section 1.3 on page 19, Go / No Go decisions are often considered as non-emergency ones because of the long duration of the projects.

In order to manage this lack of urgency, some interviewees proposed that a non-emergency situation should be considered as an emergency one, in order to decide more rapidly. For others, this approach could harm the effectiveness of a decision and increase the risk of invalidating a decision. This difference of points of view might be related to difference of personalities.

8.2.4 Categorization of the key factors in Go / No Go decisions

8.2.4.1 Presentation of the categories

After identification of the key factors, their categorization help to determine the critical activities that need to be improved, and the actors who should be involved in this improvement. The different points of view and the categories, proposed in section 7.2.2 on page 124, form the basis of this categorization. A first reading of the whole verbatim report and also of the model of the Go / No Go decision-making process, presented in fig. 5.7 on page 88, help to adapt the proposed categories to our corpus:

[6] « Une temporalité particulière : urgence masquée ... la superposition des différents processus de conception rend difficilement lisibles les échéances temporelles » [Lenfle+ 2004].

1. Π_1 = {Cause, Practice},
2. Π_2 = {Doing, Thinking, Being},
3. Π_3 = {Object, Subject, Context-Organizational factors, Context-Strategical factors, Context-External factors},
4. Π_4 = {Preparation and presentation of results and recommendations, Perception / interpretation of results, Evaluation and reasoning of results, Debate, Collaborative decision-making, Post-decisional activity, Process management},
5. Π_5 = {Project manager, Decision-maker},
6. Π_6 = {Project managers, Decision-makers, Board of directors, Chairman of the board, Project team, Marketers, Human Resource Direction, Everyone}.

The two first categories (Π_1, Π_2) are exactly the same as proposed in section 7.2.2 on page 124.

Regarding the third point of view, Π_3, a first reading of the verbatim report shows that about 50% of the key factors concern the Context category. Three sub-categories are distinguishable within the Context category in the verbatim report: strategical, organizational, and external factors. Therefore, in the case of our study, these sub-categories partition the Context category. This decomposition gives a richer categorization, adapted to our corpus, which helps to identify more precisely the areas in need of improvement.

The three last categories are adapted to the Go / No Go decision-making process in pharmaceutical R&D projects and to the actors who are in/directly involved in this process.

The categories of Π_4 are the critical activities mentioned by the interviewees in the verbatim report. Five of these activities are those in the model of the Go / No Go decision-making process, presented at two detail levels in fig. 5.2 on page 81 and fig. 5.7 on page 88. Interviewees also pointed out the causes of delay and the efficient practices related to the post-decisional activity and process management. Fig. 8.3 shows these activities:

- *Activity*$_1$: Preparation and presentation of results and recommendations, which is the last activity of the "New Information Analysis stage" (see fig. 5.2 on page 81) wherein the project manager prepares and presents the result of the tests and studies to decision-makers,
- in the ISA process, causes and practices mentioned by the interviewees mainly concern the expertise that allows actors to understand information and the decisional capacities of individuals that allow them to take a position. But these causes / practices are not clearly related to each mental activity in the framework of the collaborative choice. Therefore, in the ISA, we distinguish only two main activities that are clearly distinguishable in the interviewees' descriptions:
  - *Activity*$_2$: Perception of results, concerning comprehension of the results,
  - *Activity*$_3$: Evaluation and reasoning of results, concerning the capacity to decide, including evaluation of the results, reasoning, projection of future, and taking a position,

- in the CSA process, the interviewees point out two main activities[7]:
  - *Activity*$_4$: Debate, concerning the influences between the actors,
  - *Activity*$_5$: Collaborative decision-making: concerning decision-making itself after the debate,
- *Activity*$_6$: Post-decisional activity, some causes of delay and efficient practices, pointed out by the interviewees are post-decisional, concerning the communication of decisions made,
- *Activity*$_7$: Process management, some causes of delay and efficient practices, pointed out by the interviewees, do not directly concern the activities of the decision-making process. They concern process management, broadly defined as “the management of the processes by removing existing barriers among organizational units in enterprises or among enterprises, sharing information and management resources” [Lee+ 2010].

The set of target actors to interview, identified in section 8.1.2 on page 131 constitutes the Π_5.

A first reading of the verbatim report allows us to specify the actors who are involved in the causes of delays, or who should implement the efficient practices. These actors construct Π_6.

This annotation is illustrated by an example on a key factor, f_{192} = "mixing the information relevant to the difficulty and quantity of work performed on the project and the information relevant to Go / No Go decisions, in the presentation of results". This key factor is a cause of delay. It mainly concerns how information about the project is processed, and thus, it is related to the object. It criticizes a way of doing the activity of "Preparation and presentation of results". This key factor is pointed out by a decision-maker and is destined towards project managers. Therefore, $a(f_{192})$ ={Cause, Object, Doing, Preparation of results, Decision-maker, Project managers}.

8.2.4.2 *Results of categorization in simple categories*

From the 252 key factors pointed out by the interviewees, 44% are the causes of delay and 56% are efficient practices. This trend is the same for each group of actors, meaning that they pointed out more positive practices than causes of delay, while the questions of the grid are neutral.

Most of the key factors (77%) concern a way of doing. Only 8% of the key factors concern a way of being and 15% concern a way of thinking. A manner of doing is observable and it is easier to identify a cause of delay in decisions related to manner of doing than one related to a manner of thinking or being. At "thinking" and especially "being" levels, the key factors are not directly observable and identifiable and may be induced from a manner of doing. Additionally, identifying a key factor at "thinking" and "being" levels implies developing inner awareness, compared to the "doing" level which involves external awareness, which is easier to attain. This trend is the same for both project managers and decision-makers (see fig. 8.5).

[7] As to corridor phases, the interviewees do not propose any practices. They either consider these phases helpful to process information and make or digest a decision, or consider them as harmful to decision-making (see section 8.2.3).

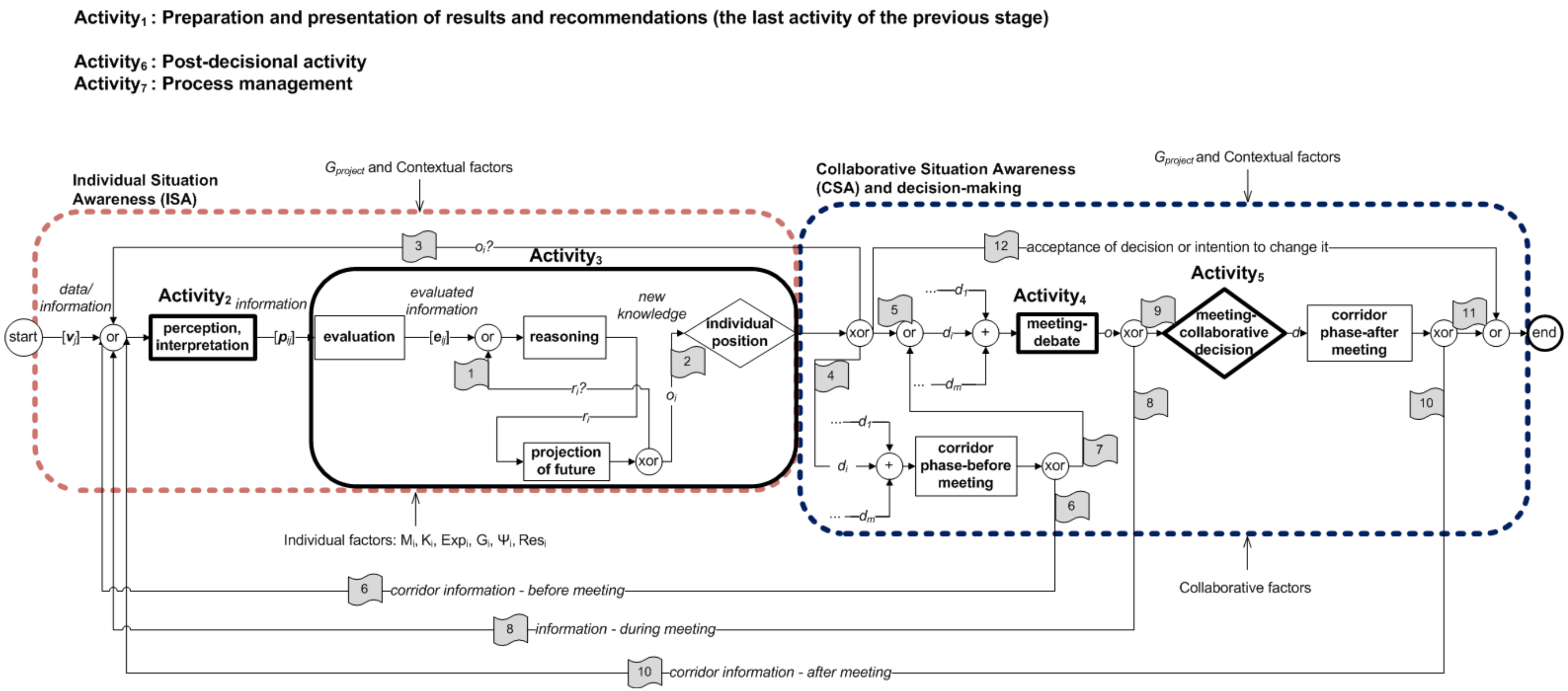


Figure 8.3: The activities, pointed out by the interviewees, which construct Π_4 including the last activity of the previous stage of the decision-making process: New Information Analysis stage (see fig. 5.2 on page 81) meaning Preparation and presentation of results and recommendations by the project manger to decision-makers ($Activity_1$), the activities of the framework for the collaborative Choice stage ($Activity_2$ to $Activity_5$) and also Post-decisional and Process management activities ($Activity_6$, $Activity_7$). The corridor phases are controversial and the interviewees do not agree about their usefulness (see section 8.2.3 on page 141).

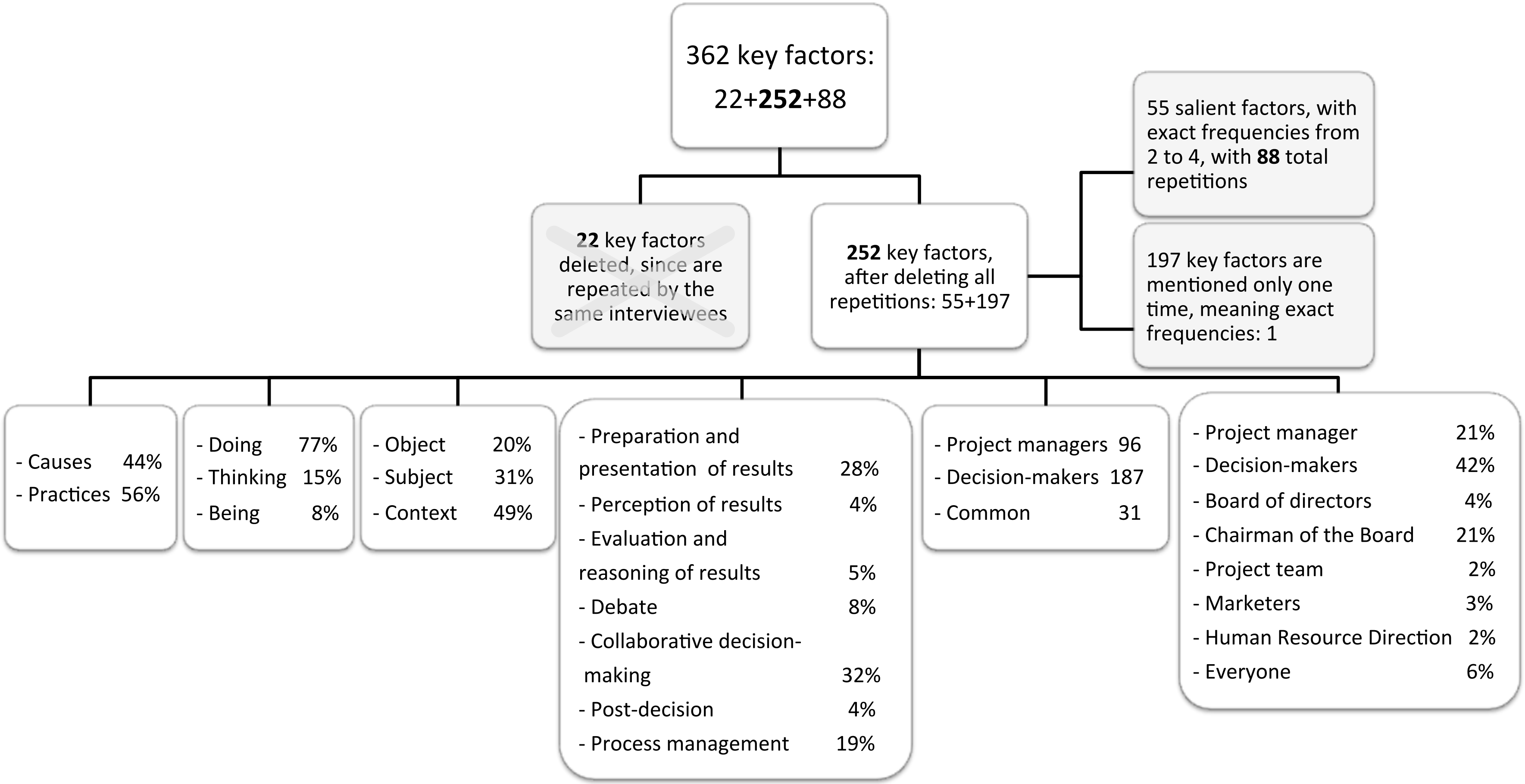


Figure 8.4: In the verbatim report, 362 key factors are identified, 22 of them are repeated by the same interviewees and are deleted. From the 340 which remain, 197 factors are mentioned only once and 55 salient factors are repeated a total of 88 times by different interviewees. The number of the key factors, excluding the repetition of the salient factors, is 252. Each of the six boxes of the third line shows the distribution of these 252 key factors according to a point of view.

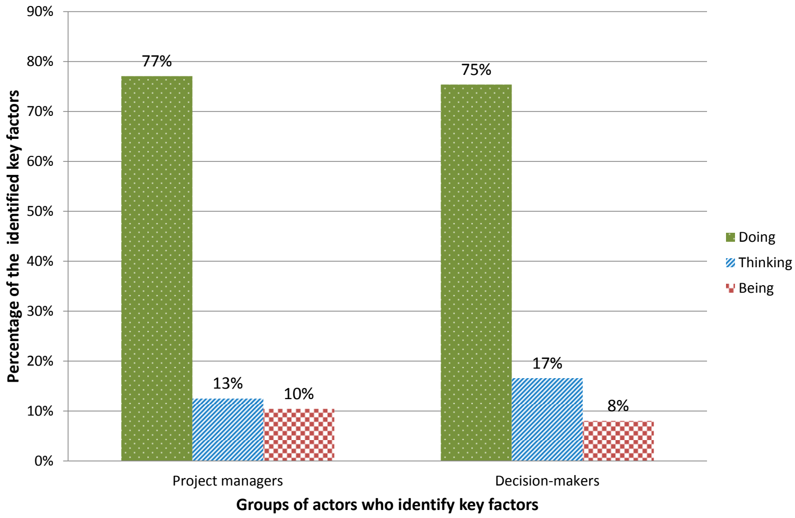
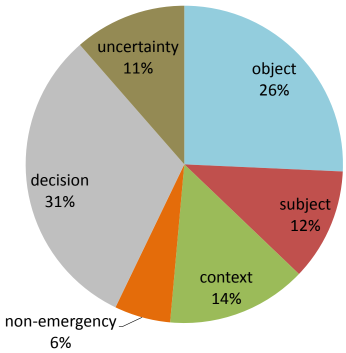


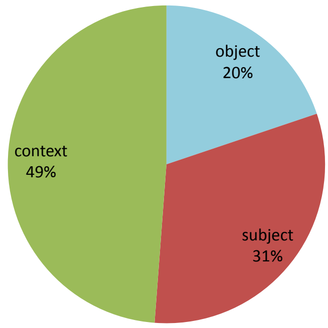
Figure 8.5: Distribution of the key factors, pointed out by project managers and decision-maker, from the point of view Π_2

Almost half (49%) of the key factors outlined by the interviewees are related to the context, 31% to the subject, and 20% to the object. Fig. 8.6 shows the distribution of the questions of the interview grid and the answers of the interviewees, for Π_3. In the interview grid, the highest percentage of the questions is on the object (32%) (see section 8.1.1 on page 129), but the highest percentage of the answers concerns the context of the companies. Decision, uncertainty, and non-emergency are the thematic axes of the interview grid but they are not the categories for the key factors. It should be noted that the key factors pointed out in answering the questions (including those about decision, uncertainty, and non-emergency) are related to one of these three categories: object, subject, and context. Thus, decision, uncertainty, and non-emergency do not appear in the pie chart of the answers. Fig. 8.6 illustrates that, in spite of the general tendency of the grid for the object, the interviewees mostly pointed out the factors related to the context. This shows a relatively weak role for the rational part (factors relating to the object) in the difficulty and delay of Go / No Go decision-making, compared to factors relating to the context and subjects which need to be resolved. The high number of contextual key factors leads us to categorize them in order to understand what points cause the problem in the context and what areas need to be improved. In this regard, we distinguish three categories within the Context category:

- Context-Organizational factors (11%): factors that concern organization in terms of time, resources, and especially, the holding of decision meetings - such as how to begin and end these meetings,
- Context-Strategical factors (35%): factors related to strategy and governance of an enterprise that create its culture,
- Context-External factors (3%): factors related to the external environment of enterprises such as the market, regulation, etc.



(a) Questions of the interview grid



(b) Answers of the interviewees

Figure 8.6: On the left, percentages of the questions in the thematic axes of the interview grid: object, subject, context, decision, uncertainty, and non-emergency of the situations, and on the right, percentages of the key factors in the verbatim report regarding Π_3: object, subject, and context categories.

The same trend is observed for both groups of actors, regarding Π_3: fig. 8.7 shows that both project managers and decision-makers underlined roughly equal percentages of the key factors in each category.

The distribution of the key factors regarding the critical activities of the decision-making process shows that 79% of the causes and practices underlined concern three activities which are thus, considered the most problematic: Preparation and presentation of results 28%, Collaborative decision-making 32%, Process management 19%. The other factors concern: Perception of results 4%, Evaluation and reasoning of results 5%, Debate 8%, Post-decisional activity 4%. This distribution shows the importance of the collaborative activities (Decision-making itself preceded by Debate) and Process management, which defines the working environment.

In sum, 96 and 187 key factors are pointed out respectively by 3 project managers and 4 decision-makers.

Most of the key factors are aimed at decision-makers: Project managers 21%, Decision-makers 42%, Board of directors 21%, Chairman of the board 4%, Project team 2% Marketeers[8] 3%, Human Resource Management 2%, Everyone 6%. Tabs 8.4, 8.5, and 8.6 show some examples of the causes and practices aimed at project managers, decision-makers, and the board of directors.

8.2.4.3 *Results of categorization in cross-referenced categories*

In this section, by cross-referencing the categories of different points of view, we answer the following questions. Are the key factors concerning the critical activities

[8]The role of marketing in the pharmaceutical industry is different from its role in developing new products in other industries. In this regard, Becker+ 2006 highlight six traditional roles of the marketeers which differ in the field of developing new medicines: 1) understanding consumer needs, 2) marketing as source of innovation, 3) translating consumer needs into workable products, 4) testing product concepts and prototypes, 5) forecasting. The different roles of marketeers in the pharmaceutical industry cause some difficulties between them and the R&D actors.

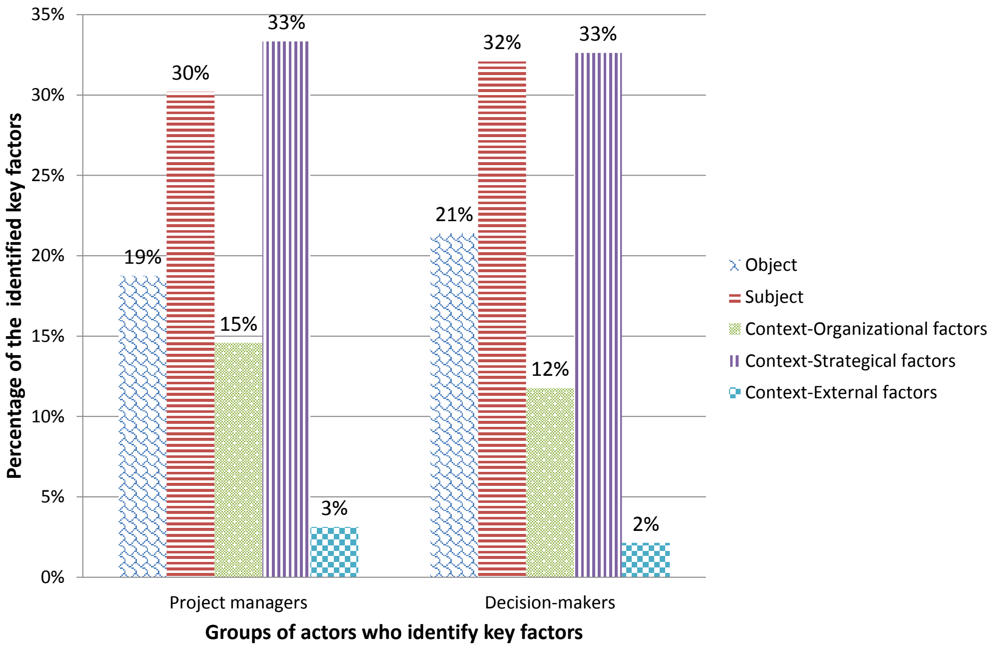


Figure 8.7: Distribution of the key factors, pointed out by project managers and decision-maker, from the point of view Π_3

mostly to be found in object, subject, or context categories? What are the common key factors pointed out by both project managers and decision-makers? What are the mutual criticisms of project managers and decision-makers?

Factors related to the Preparation and presentation of results are mainly related to the object class (65%). Factors related to Collaborative decision-making and Process management are mostly contextual (respectively 69% and 72%). This is explained by the fact that the Presentation of the results is an individual activity, based on factual results wherein the key factors are related to information, while Collaborative decision-making and Process management involve more factors relating to the context and subjects.

Collaborative decision-making involves some factors relating to the subjects (28%), but depends more significantly on the context (69%). Analysis of the contextual factors shows that 3% of them are external, 21% organizational, and 44% are related to the governance and culture of the enterprise. In the same way, the analysis of the contextual factors related to Process management shows that 2% are external, 4% organizational, and 65% are related to governance. This same trend is observed for both project managers and decision-makers with respectively 51% and 47% of the key factors related to the context.

The important role of a leadership and organizational context, which can value and nurture the emergence and implementation of efficient practices, is outlined in the literature [Cooper 1998; Kerzner 1998; Charan 2001; Loo 2002; Davenport 2009]. This study confirms the important role of the context in delays in decision-making, identifies the causes of delay directly related to the context, and proposes efficient practices to reduce this delay.

Table 8.4: Examples of causes of delay and efficient practices, destined towards project managers

Causes of delay	**Efficient practices**
Mismatching of the interpretation of raw data with the level of expertise of decision-makers.	Adapting the contents to the knowledge level of the audience (decision-makers).
Mixing information relevant to the quantity of work and that relevant to Go / No Go decisions.	Selecting only the information relevant to Go / No Go decisions.
Inappropriate level of detail.	Adapting the level of detail non-homogeneously, emphasizing the questionable results.
Lack of link between contradictory information.	Highlighting eventual contradictions.
Delay in sending the results to decision-makers.	Sending the results to decision-makers in time in order to prepare decisions.
Amplification of positive results.	Presenting both negative and positive results with the same emphasis.
Lack of belief-sharing.	Presenting the results with conviction.

From 252 key factors, 31 are pointed out by both project managers and decision-makers, such as: difficulty of jargon in such a multidisciplinary field, difficulty of No Go decisions, and lack of management of the end of life of stopped projects. This last factor, against all expectations when the purpose is to reduce delay, consists in delaying No Go decisions to allow time for detachment from the projects and to digest their past costs. Some "planned" lost time is better than invalidating a brutal No Go decision *a posteriori*.

The main mutual criticism of the decision-makers and project managers is as follows. On the one hand, while much attention is quite rightly paid to the way in which the tests are performed and the results are provided, little attention is given to the way in which the results are interpreted, aggregated, prepared, and presented. "Preparation and presentation of the results is not considered as a *real* activity and the necessary time and resources are not allocated to it", as one decision-maker affirms. On the other hand, as one project manager emphasizes, "decision-makers skip debate and discussion. They are not trained to make collaborative decisions, especially when faced with uncertainty".

Project managers outlined twice as many key factors destined towards decision-makers (42%) as those destined towards themselves (21%). This trend is reversed for decision-makers with 43% of the factors aimed at themselves and 23% towards project managers. Three explanations are possible: 1) the role of the project manager in the critical activities is contained only in Preparation and presentation of results, while decision-making is represented through several activities, 2) the self-criticism of the decision-makers can be explained by the maturity and broad experience of this group of actors. It can be illustrated by some key factors related to "Collaborative

Table 8.5: Examples of causes of delay and efficient practices, destined towards decision-makers

Causes of delay	Efficient practices
Lack of preparation of the decision meeting.	Reading the results sent and prepare the decision meeting.
Silence in the case of lack of understanding caused by technical jargon.	Asking questions, in the case of lack of clarity of the presentation.
Lack of reciprocal interactions in the steering committee.	Listening, but also express opinions and argue.
Conformism in the steering committee.	Expressing one's opinion, even if it varies from the tendency of the group.
Inevitable loss involved in each decision.	Accepting that making a decision implies losing an option.
Difficulty of No Go decisions.	Giving the project team enough time to digest a No Go decision.
Lack of clarity in the formulation of decisions.	Formulating decisions clearly at the end of the meetings.

decision-making", underlined by decision-makers only: lack of concern from some decision-makers whose participation lasts less time than the duration of the projects, "fastfood decisions" due to the lack of deliberation and maturation processes, etc., 3) decision-makers participate jointly in the Choice and Review stage (see fig. 5.2 on page 81) and therefore, can observe and criticize the practices of their colleagues, contrary to a project manager who is the main actor of his own activity (Preparation and presentation of results) and does not have the opportunity to participate in meetings with other project managers. Therefore, project managers have more opportunity to criticize the decision-makers.

Tab. 8.4 shows some examples of the practices destined towards the project managers, concerning the activities of Preparation and presentation of results and recommendations. Tab. 8.5 shows some examples of the practices destined towards decision-makers for the activity of Collaborative decision-making.

Some practices destined towards project managers and decision-makers cannot successfully be implemented without the necessary contextual and organizational support. For example, "psychological safety" [Edmondson 1999] should be in place to allow each individual to be direct in expressing opinions. The important role of leadership and organizational context is also outlined in the literature. Efficient practices emerge in an organizational culture that values and nurtures these practices [Cooper 1998; Kerzner 1998; Charan 2001; Loo 2002; Davenport 2009].

Project managers and decision-makers destined respectively 21% and 20% of the factors to the board of directors. Tab. 8.6 gives some examples of efficient practices, concerning governance of an enterprise, destined to the board of directors, in three classes: strategy, work environment, and organization.

As with any interview-based approach, the subjectivity of the interviewers and interviewees is an unavoidable weakness. We have tried to reduce it as much as possible by cross-referencing different the points of view of the interviewers at three points in the study: 1) designing the study, interview grid, and analysis plan, 2) conducting interviews, and 3) analyzing results. As for interviewees, we have tried to identify and clearly the convergences and divergences of their opinions regarding their roles in the decision-making process. For example, the multiple repetitions of the different aspects of fear of hierarchy, fear of uncertainty, lack of belief-sharing, etc. are the relevant indicators of the problems concerning these factors.

These practices have been reviewed and validated by the actors of the both groups (decision-makers and project managers) and also by our industrial partner. The results of the interviews help each group of the actors to take into account the expectations of the other group and help make collaborative decisions more effective and faster.

Table 8.6: Examples of causes of delay and efficient practices destined towards the board of directors

Causes of delay	Efficient practices
Strategy	
Ambiguity of the global strategies.	Clarifying, communicating, and explaining global strategies to decision-makers and project managers and ensure their comprehension.
Mismatching of the composition of the steering committee with the global strategies.	Adapting the composition of the steering committee to global strategies.
Wearing effect of the steering committee.	Reviewing the composition of the steering committee.
Lack of clarity of the modality of decision-making.	Specifying clearly who really make/s the final decisions.
Lack of communication on the decisions made.	Communicating and explain the decisions made.
"Putting all your eggs into one basket in an uncertain environment", as one decision-maker puts it.	Diluting uncertainty by developing the back up and follow up projects or diversify the portfolio by licensing opportunities.
Lack of clarity of the responsibilities of different committees.	(Re)defining, communicating, and explaining the perimeter and scope of each committee.
Work environment	
Fear of hierarchy, especially since there are several hierarchical levels within the steering committees.	Creating a safe environment, especially within the steering committee.
Lack of confidence.	Trusting and asking for responsibilities.
Lack of implementation and respect of new measures by the superior hierarchical levels.	Implementing efficient practices at all hierarchical levels.
Organization	
Lack of time and resources to prepare the presentation.	Allocating sufficient resources to prepare the results.
Tele-decision-making.	Avoiding tele-decision-making.
Short and ill-organized debate.	Organizing four key periods in decision meeting: debate, deliberation, decision, communication.
Lack of traceability of decisions.	Storing a summary of the information related to decisions and also the way decisions were made.

Conclusion - part III

This part investigates the causes of delay in difficult collaborative Go / No Go decision-making, when faced with uncertainty, in pharmaceutical R&D projects and also the efficient practices to reduce delays.

A methodology, based on in-depth interviews, is proposed to identify and structure the key factors that affect the decision-making process. This methodology includes the construction of an interview grid, the identification of the target actors, and an analysis plan of the verbatim report of the interviews. This plan is composed of two steps: 1) identifying the salient factors and controversial factors that are involved in delays in the decision-making process, 2) structuring the key factors according to the activities of the decision-making process, the actors who pointed out these key factors, and those who should take these factors into account in performing their activities. This helps to identify the activities that should be improved, specifying who should improve them and how.

This methodology is applied to the problem of delay in Go / No Go decisions in drug development projects. Two groups of major actors in Go / No Go decision-making are interviewed: 3 project managers and 4 decision-makers. A verbatim report of 18,200 words is constructed which highlights the causes of delay. In the verbatim report, 111 causes of delay are identified and 141 efficient practices are proposed that are based on the feedback of actors with many years of experience.

The results show all the interviewees agree that Go / No Go decisions are frequently delayed or invalidated, or some of them are never made and the projects are "left to rot", as one project manager puts it. Two activities of the decision-making process, most cited by the interviewees are Preparation and presentation of results and Collaborative decision-making. The same tendency is observed within project managers and decision-makers. We conclude that while much attention is quite rightly paid to the way in which the tests are performed and the results are provided, little attention is given to the way in which the results are aggregated, prepared and presented, and to how decisions are made. In sum, Preparation and presentation of results and Collaborative decision-making are presumed to be *natural* activities that do not need training, practice, or even the necessary time to be performed.

Inadequate interpretation of the results of the tests, information overload during the decision meetings, lack of debate and deliberation are some causes of delay directly linked to the activities of the model of Go / No Go decision-making process. But the three most-mentioned factors involved in decision delay are not directly related to

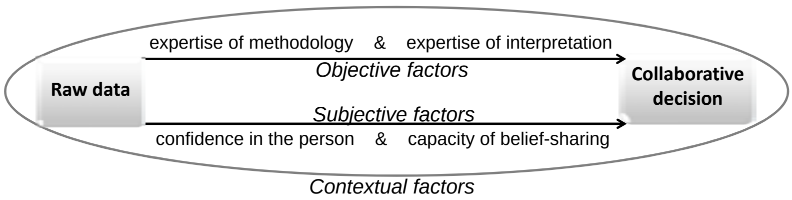


Figure 8.8: Trajectory of a collaborative decision

the activities of the decision-making process: fear of uncertainty, fear of hierarchy, and difficulty of No Go decisions.

Three compendiums of practices are destined towards the project managers, decision-makers, and the board of directors that would allow collaborative decisions to be formed, matured, digested, respected, and finally executed. Fig. 8.8 summarizes the trajectory of a collaborative decision from the raw data to the decision itself. When the raw data is interpreted and presented by a project manager to decision-makers, factors related to the object and subjects are involved in forming the decision. The factors related to the object include the expertise of the project manager in the methodology of producing data and its interpretation. The factors related to subjects include the confidence of decision-makers in the project manager, which is based on previous experiences, and also the capacity of the project manager to share his beliefs and convictions when faced with uncertainty.

The causal factors and efficient practices, identified by the actors, are at three levels: being, thinking, and doing. The congruence of these levels helps: 1) a project manager or a decision-maker to share knowledge and belief and reach a compromise, 2) in making a decision effectively and rapidly, and communicating, explaining, executing, and respecting it. If there is no congruence, a sense of conviction is not established within a group, and decision-makers may look for excuses to postpone the decision, or try to change it. Thus, dissonance in these levels slows down belief-sharing and the decision-making process and the alignment of these stages helps in implementing efficient practices. This may explain why efficient practices cannot sometimes be successfully implemented. It is not enough to change a practice at the "doing" level. It should be explained in order to be changed (at least) at the "thinking" level. However, we think that changes are more difficult (if not impossible in certain cases) at the "being" level.

The results are limited to the problem of delay in difficult Go / No Go decisions in the pharmaceutical industry. The sample covers only the R&D actors who contribute to these decisions. The size of the sample is limited, because of: 1) the rarity of difficult Go / No Go decisions, 2) the rarity of decision-makers and project managers who are the actors with a high level of expertise, 3) the sensitivity of the subject (public health), 4) a high degree of confidentiality in R&D projects in general and in the pharmaceutical sector particularly, 5) the nature of our questions (pathological study of decision-making) that implies criticizing oneself, colleagues, companies, and even banks and politicians, 6) the form of our questions (open, neutral and descriptive ones) that take a lot of time and are more difficult to answer, compared to multiple-choice questions, and the number of questions (35).

General conclusion

A conclusion is the place where you get tired of thinking.
Arthur Bloch

Pharmaceutical R&D projects are composed of several phases of trials wherein the safety, efficacy, and quality of new compounds are progressively tested. Trials and studies are piloted by a project manager who presents the results of the studies to a group of various experts who have to decide whether the new molecule's development should be continued or stopped. These Go / No Go decisions are based on benefit-risk balances that can be very *easy* to assess if the results are very *bad*, for example when a molecule may be toxic and its safety is questionable, or if the results are very *good*.

In the other cases, benefit-risk balances are very difficult to assess. This difficulty is due to the uncertainty and complexity of the multidisciplinary results of tests, involving the contribution of several experts which may delay reaching a compromise. Additionally, the results of the tests of a new compound on thousands of patients are sometimes not predictive enough to assess the risks and benefits for the millions of patients who may use a drug after its commercialization. Another point that complicates these decisions is the competitiveness of molecules compared to the existing medicines on the market or to products being developed by competitors. Moreover, Go / No Go decisions are made throughout long-lasting projects and in non-emergency situations, which may induce decision-makers to defer decisions and tolerate some delays.

In this context, a recurrent delay is manifested either by lengthy suspension of decisions or by frequent invalidation of decisions made. Delay in decision-making adversely affects meeting the goals of these high-cost, high-risk, and long projects. To improve public health and to push projects forward, delays in decision-making should be reduced. The aim of this thesis has been to identify the causes of delay and the efficient practices (the way the actors perform their activities) that help reduce it.

In the first part, we presented an overview of the increasing pressures on decision-makers in the pharmaceutical industry caused by rapid changes that, while offering new perspectives in R&D, also complicates Go / No Go decisions. We described the difficulties in assessing benefit-risk balances of new compounds on which Go / No Go decisions are based. We distinguished two types of difficulties in assessing a benefit-risk balance: objective difficulties, meaning those related to the quality and quantity of information that should be taken into account in the balance, and subjective difficulties, meaning those related to personal visions and preferences which make this judgment, like any other, subjective. All these elements help understand the context wherein Go / No Go decisions are made.

To better understand delay in decision-making when faced with uncertainty, we have reviewed the notion of uncertainty. Through an etymological study, we pointed out that uncertainty and decision have the same root, coming from a Latin verb literally meaning "to cut off". A notion of loss, *not possessing a whole after cutting*, is implicit in decision and uncertainty.

We underlined two approaches to defining uncertainty: object-based and subject-based approaches, and propose an encompassing definition of uncertainty that brings together these approaches, since, in the study of the causes of indecision under uncertainty, both causes relating to the object and those relating to the subject should be considered. Context and time are two other key elements that we have taken into account in our definition, for the same reason: they may have an impact on delay. As regards uncertainty, it may be that object-based approaches are appropriate in mathematics, AI, or economics, and subject-based approaches are pertinent in psychology. But we defend the idea that in project management, we cannot separate subject (actors), object (project), context, and time. Therefore, for us,"uncertainty is a subject's conscious lack of knowledge about an object, which is not yet clearly known, in a context requiring a decision (an action) within a certain time frame".

We have reviewed the notion of indecision in the literature. We classified the causes of indecision according to subject (decision-maker(s)), object or event (available information about the state of an object or the occurrence of an event), and context (situation of decision-making).

This classification led us to four conclusions: 1) contrary to uncertainty which has a history as old as the Antiquity, indecision is a more recent notion which is less widely considered in the literature, 2) existing studies are mostly performed in psychology and focus on the individual causes of delay relating to subject. Indecision is less studied in the context of groups, 3) limits on the quality and quantity of information about an object or an event are mentioned as a cause of indecision by some authors in the indecision literature. With no link to human indecision, limits on the quality and quantity of information have been widely studied in AI, 4) as some recent research works indicate, the role of the organizational context is less widely considered in the literature. This bibliographical study confirms the need to improve and accelerate decision-making in organizations and the lack of studies about indecision.

In the second part, to investigate the problem of delay, the Go / No Go collaborative decision-making process was modeled. This model presented, in three levels of detail, the stages of the Go / No Go decision-making process: 1) Intelligence and Design stage, 2) Test stage, 3) New Information Analysis stage, and 4) Choice and Review stage.

In this model, at the first level, the hierarchical positions of the actors and the information flow are visualized, including both descending and ascending information, from the superior hierarchical levels to lower levels and *vice versa*. Descending information becomes more detailed and complete when arrives at the level of the technicians, who will carefully perform tests, following certain protocols. Ascending information becomes aggregated when it arrives at the level of the steering committee who make the decision. In the second level of detail, the activities of each stage are detailed. These two levels of detail highlight the collaboration between the actors who produce and prepare information and those who consume it in order to decide. To take into account the collaboration between decision-makers and also to describe how they process information and interact with each other, a third level of detail is needed for the Choice stage.

A framework of the collaborative Choice stage was thus proposed which includes both "individual reflection" and "group interaction", respectively through Individual Situation Awareness (ISA) and Collaborative Situation Awareness (CSA). The ISA formalizes the transformation of data into information, and then into knowledge through the individual cognitive processes: perception, evaluation, reasoning, and projection of the future. Fuzzy sets and fuzzy inference rules were used to model human evaluation and reasoning with uncertain values. The CSA visualizes the interactions between decision-makers through corridor phases (informal discussions), debate (formal discussions), and decision-making. The framework: 1) makes explicit differences and similarities of the information processing by different decision-makers who take a position before the collaborative steps, 2) reveals the interactions within a group which may reinforce or question an individual position and propagate doubts and beliefs, 3) simulates individual and collaborative behavior which depend on the individual cognitive processes and the positions of the individuals in the group, 4) measures the risk of invalidating a decision through the dissatisfaction of the decision-makers. Thus, we have been able to analyze conflicts in past decisions and anticipate future conflicts.

However, in the collaborative Choice stage, some questions remain unanswered and some influential factors remain to be determined: are their current practices efficient, or are some changes necessary to improve and accelerate the decision-making process? What are the roles of the influential factors such as "task and environment factors" on their practices? The model of the decision-making process cannot directly answer these questions, but it can be used as a baseline to collect information about them through an interview-based approach.

In the third part, we thus aimed to identify the key factors that affect decision-making in an enterprise through interviewing industrial actors. In-depth interviews with descriptive and open questions are powerful tools to explore complex experiences, in that they reduce the possibility of influencing the interviewees. Therefore, an in-depth interview-based approach was taken to collect actors' feedback, and to cross-reference and analyze their opinions and recommendations on delays in the decision-making process.

In this study, a small size sample was used, because of: 1) the rarity of difficult Go / No Go decisions, 2) the rarity of decision-makers and project managers, who are those actors with a high level of expertise, 3) the sensitivity of the subject (public health), 4) a high degree of confidentiality in R&D projects in general and in the pharmaceutical sector particularly, 5) the nature of our questions (pathological study of decision-making) that implies criticizing oneself, colleagues, companies, and even banks and politicians, 6) the form of our questions (open, neutral and descriptive ones) that take a lot of time and are more difficult to answer, compared to multiple-choice questions, and the number of questions (35).

The sample covered only the R&D actors who contribute to these decisions. The results were limited to the problem of delay in difficult Go / No Go decisions in the pharmaceutical industry. As with all interview-based approaches, the subjectivity of the interviewers and interviewees is an unavoidable weakness of this study. We have tried to reduce it as much as possible by cross-referencing opinions, pointing out clearly their convergences and divergences.

Two groups of major actors in Go / No Go decision-making were interviewed: 3 project managers and 4 decision-makers. A verbatim report of 18,200 words was then constructed from 26 hours of interviews wherein 111 causes of delay and 141 efficient practices were identified based on the actors' feedback.

The results show all the interviewees agree that difficult Go / No Go decisions are frequently delayed or invalidated. The three most-mentioned causes of delay are not directly linked to the activities of the decision-making process: fear of uncertainty, fear of hierarchy, and the difficulty of No Go decisions. The other factors that affect delay, sorted in order of their total frequency in the verbatim report, are: lack of belief / conviction-sharing process, not sending the results to decision-makers early enough before the decision meeting, lack of complete interpretation of the results, information overload in decision meetings, short and ill-organized debate, difficulties caused by jargon, lack of risk analysis, and lack of round table discussion to collect comments. Different aspects of all these factors were pointed out between 5 to 22 times by the interviewees.

The most cited factors concerned two activities of the decision-making process: Preparation and presentation of results performed by project managers and Collaborative decision-making done by decision-makers. We conclude that while much attention is quite rightly paid to the way in which the tests are performed and the results are provided, little attention is given to the way the results are interpreted, aggregated, prepared and presented, and to the way decisions are made. Preparation and presentation of results and Collaborative decision-making are presumed to be *natural* activities that do not need training, practice, or even the necessary time to be performed.

In sum, this thesis contributes to:

– identifying and clarifying the problem of delay in decision-making where an immediate decision is not necessarily needed, as it would be the case in crisis situations. Sometimes, researchers and industrial actors may not take into consideration the need to improve decision-making in non-emergency situations, supposing that "if we know how to make decisions in emergency situations, we know how to do it non-emergency ones"[9]. However, our study shows that this is not always true and the mechanisms that intervene in decision-making in non-emergency situations are a worthy subject of research,
– clarifying the notions of uncertainty in project management and indecision in organizations, taking into account the role of object, subject, context, and time in their generation and treatment,
– visualizing and analyzing the information used and the process applied to making collaborative decisions, as this process is modeled, including its underlying information life cycle,

[9] We have heard this argument used during a debate in a conference.

- identifying 252 factors that affect the quality and speed of decision-making processes in organizations. Based on these factors, three compendiums of practices are destined towards the project managers, decision-makers, and the board of directors that would allow collaborative decisions to be formed, matured, digested, respected, and finally executed, in non-emergency situations in a safe work environment,
- highlighting the collaborative decision trajectory from information to decision *via* both methodological expertise and capacity to create confidence and share beliefs when faced with uncertainty,
- distinguishing three levels of being, doing, and thinking in the factors that affect decision-making. This helps in understanding the different levels of difficulty involved in implementing efficient practices.

Possible future directions for this study might include first, developing a multiple-choice questionnaire on the key factors identified, in order to examine the results obtained on a larger number of actors. Secondly, constructing an evaluation grid of the quality of the decision-making process in organizations, to anticipate the problem of indecision. Thirdly, identifying the obstacles to implementing efficient practices, so as to develop an action plan for these changes, and to adopt change management methods in order to assist the actors in making the changes.

Résumé des travaux en français

La langue anglaise est un fusil à plombs : le tir est dispersé. La langue française est un fusil qui tire à balle, de façon précise.
Otto von Habsburg

Cette thèse est organisée en trois parties. La première partie commence par la présentation de la problématique de retard dans la prise de décision face à l'incertitude. Les décisions étudiées concernent la poursuite ou l'arrêt de développement de nouveaux médicaments. Ces décisions, appelées Go / No Go, sont ensuite modélisées dans la deuxième partie. Le processus modélisé est utilisé pour une étude de terrain sur les causes du retard, dans la troisième partie de ce travail.

Retard dans la prise des décisions Go / No Go

Dans la première partie, les particularités des projets de développement de nouveaux médicaments sont expliquées. Ces particularités impliquent une forme très particulière d'innovation, qui rend la prise de décision de plus en plus difficile. Une étude bibliographique est ensuite présentée sur les thèmes clés de cette étude : incertitude et indécision.

Particularités des projets de développement de nouveaux médicaments

Un médicament, avant d'arriver sur le marché, passe par plusieurs phases de tests et d'études qui visent à démontrer sa sécurité, son efficacité et sa qualité. Les projets de R&D pharmaceutiques sont de longue durée (plus de 13 ans), très coûteux (près de 900 M$) et très risqués (avec un taux de succès de seulement 4 %) [Paul+ 2010]. À la fin de chaque phase, un comité d'experts de différents domaines se réunit pour statuer sur la poursuite ou l'arrêt du développement de la nouvelle molécule. Une décision Go / No Go doit donc être prise sur la base des résultats des tests qui deviennent progressivement plus complets et exacts lorsque les projets avancent. Cependant, pour faire évoluer les projets, les décisions Go / No Go doivent parfois être prises sur la base de résultats incomplets et d'informations incertaines.

Dans ces situations, l'information incertaine est souvent perçue différemment par les experts des différents domaines impliqués dans le processus de prise de décision. En conséquence, les décisions peuvent être soit ajournées jusqu'à ce que les décideurs atteignent un compromis, soit invalidées *a posteriori*.

Les coûts de R&D pharmaceutiques sont très élevés comparativement à d'autres industries : ils représentent plus de 12 % des Chiffres d'Affaires (CA) des entreprises pharmaceutiques. Cette valeur ne représente que 4,2 % de CA dans l'industrie d'automobile [LEEM 2008]. De plus, ces coûts ne cessent d'augmenter et atteignent une moyenne de 17 % de CA en 2010 [Bohineust 2010]. « Pour limiter l'augmentation des dépenses de santé liées à la multiplication de nouveaux médicaments, les autorités régulatrices tendent aujourd'hui de plus en plus à refuser l'autorisation de mise sur le marché de produits dont les effets sont proches d'autres qui existent déjà » [Midler 2004]. Selon la Food and Drug Administration (FDA), le seul habilité à autoriser la commercialisation des médicaments sur le territoire des États-Unis, « sur 250 molécules au stade préclinique, nécessitant déjà 6 ans environ de recherche, seule une sera approuvée. Et sur 5 molécules entrant en phase clinique, après 16 ans de R&D seule une sera approuvée par la FDA »[10] [Weinmann 2008].

Dans ce contexte, la vitesse devient un critère tout à fait déterminant. Arriver le premier sur le marché des nouveaux médicaments pour une indication thérapeutique donnée est donc décisif, pour « la prime économique que donne naturellement cette position » [Midler 2004], mais aussi pour compenser les coûts des molécules dont les développements ont été arrêtés. Le coût considérable induit par les retards finaux ou les invalidations de décisions, en termes d'effort humain, d'investissements financiers et de temps, crée un besoin de révision de processus de décisions Go / No Go. Et donc pour répondre à ce besoin, notre étude porte sur les causes du retard et les pratiques actuelles dans la prise de décision sous incertitude, de même que les pratiques efficientes qui aident à réduire ce retard.

Caractéristiques des décisions Go / No Go

La prise de décision est un ensemble de processus cognitifs visant à choisir une option parmi un ensemble de choix. Le décideur effectue son choix en comparant les conséquences des différentes options. Dans le cas de notre étude, les dimensions qui caractérisent le contexte d'un tel choix, sont les suivantes :

– incertitude : la balance bénéfice-risque des différentes options est d'autant plus sujette à discussion lorsqu'on se trouve en situation inconnue. Le manque de connaissance des choix possibles et de leurs conséquences entraîne l'incertitude chez les décideurs, ce qui met en danger l'efficacité et la rapidité de décision. Ce réflexe de reporter la décision dans l'attente d'une nouvelle information réductrice de l'incertitude est très souvent observé afin d'orienter le choix vers une option,
– aspect non urgent : la décision à prendre ne semble pas présenter de degré d'urgence apparent, mais un danger pourrait apparaître à long terme. D'où l'originalité de ce travail, car plusieurs travaux de recherche sont menés sur le thème du risque et de l'incertitude dans une situation d'urgence tel que l'on peut rencontrer dans le cas d'une crise économique [Sinclair 1985], politique [McDermott+ 2002], humanitaire [Charles 2010], etc. Par contre, les phénomènes du risque latent et non menaçant sont relativement peu étudiés. Les choix d'investissements, de renouvellement d'équipement, de modernisation d'unité, la mise en place de nouveaux dispositifs de sécurité sont autant de situations qui peuvent relever de ces décisions sans degré d'urgence. Il est tout à fait possible de surseoir à la décision et de différer dans l'attente d'éléments plus probants dans un contexte de prise de risque. Dans

[10] http://www.dgcis.redressement-productif.gouv.fr/files/files/archive/www.industrie.gouv.fr/biblioth/docu/dossiers/sect/etude_pharma.pdf

le cadre des projets de développement de nouveaux médicaments, la longue durée des projets peut laisser penser que les décisions Go / No Go ne sont pas urgentes. Ici, contrairement aux situations urgentes, les conséquences des décisions ne peuvent être connues qu'après dix ans,

– aspect collaboratif : la décision collaborative est le résultat d'un débat d'experts. La personnalité de chacun, son mode de raisonnement, son goût pour le risque ou son caractère prudent et précautionneux, son intérêt personnel et son degré d'implication dans la suite de projet constituent autant de possibilités d'influences sur le collectif et contribuent à des interactions entre les décideurs, ce qui complexifie le processus décisionnel.

État de l'art

Pour comprendre le problème du retard dans la prise de décision sous incertitude, nous étudions tout d'abord les notions d'incertitude et d'indécision.

Définitions de l'incertitude

Notre étude montre que l'incertitude a la même racine étymologique que la décision ; toutes les deux viennent du verbe couper / trancher. Il est frappant de constater que l'incertitude et la décision, qui sont deux concepts fortement liés dans la pratique, proviennent de la même racine. Notons que cette racine révèle la pénibilité de l'action de décider causée par la perte (il n'est jamais agréable de trancher quelque chose).

Nous identifions ensuite deux approches dans la définition de l'incertitude :

– une première approche, adoptée en économie, qui définit l'incertitude en mettant l'accent sur le manque d'information à propos d'un objet dont l'état évolue ou à propos de l'occurrence mal connue d'un évènement : manque d'information sur la probabilité des différentes issues [Knight 1921], la différence entre l'information dont on dispose et celle dont on a besoin [Galbraith 1973],
– une deuxième approche, adoptée en psychologie, qui définit l'incertitude en mettant l'accent sur l'état mental d'un sujet caractérisé par un manque de connaissance : la réaction mentale d'un humain face à l'environnement extérieur, accompagné d'un sentiment de doute qui bloque ou retarde l'action [Thompson 1967 ; Head 1967 ; Lipshitz+ 1997].

En management de projet, l'objet, le sujet et le contexte jouent des rôles importants dans la génération, la caractérisation et le traitement de l'incertitude. Nous proposons donc une définition élargie de l'incertitude, qui prend en compte les facteurs relatifs à l'objet, au sujet et au contexte.

> L'incertitude est un manque conscient de connaissance d'un sujet, relative à un objet, non encore parfaitement défini, dans un contexte nécessitant une décision / action dans un certain laps de temps. [Hassanzadeh+ 2012a].

Si après un certain temps attendu le sujet n'arrive pas à décider et à mener une action, il peut être dans le cas d'indécision.

Causes d'indécision

L'étude bibliographique sur l'indécision montre que cette notion, par rapport à la décision et à l'incertitude, est nouvelle en recherche. À titre d'exemple, si on effectue une recherche avec « indecision OR indecisiveness » comme mots clés sur le site ScienceDirect, on n'obtient que 35 articles. Sur le même site, il existe 17 154 articles avec le mot clé « decision » et 8 922 articles avec le mot clé « uncertainty ». La même tendance a été observée sur les autres sites de recherche des articles scientifiques comme Springer.

Les études existantes sur l'indécision ont majoritairement été effectuées, en dimension individuelle, en psychologie. Les causes liées à la qualité et la quantité de l'information sont largement étudiées en Intelligence Artificielle (IA). Nous classifions les causes d'indécision selon les éléments clés suivants : sujet, objet et contexte (*cf* tab. A.1 en annexe).

À cet égard, des articles récents indiquent un manque d'études sur l'indécision dans les entreprises et les organisations [Charan 2001 ; Davenport 2010 ; Denis+ 2011 ; Brooks 2011 ; Akdere 2011 ; Patalano+ 2011].

Modélisation de processus de décisions Go / No Go

Afin de décrire, visualiser et formaliser le processus de prise de décision, ainsi que la problématique du retard, nous modélisons le processus de prise de décision dans les projets de R&D pharmaceutiques. La Figure 5.1 illustre la vision globale du modèle. Dans ce schéma, nous distinguons trois dimensions qu'il convient d'étudier pour modéliser ce processus de décision :

- les quatre macro-étapes du processus de décision, illustrées par des grandes flèches qui entourent la pyramide :
  1. collecte de l'information et conception,
  2. réalisation de tests,
  3. analyse de nouvelles informations et
  4. choix,
- les acteurs qui participent au projet, comme les techniciens, les chefs de métier, les experts internes ou externes, le chef du projet et le comité de pilotage,
- le flux d'information entre les acteurs, illustré par des petites flèches.

Le schéma permet de visualiser le rôle de chaque acteur dans la création, la circulation et l'évolution de l'information qui :

- descend du comité de pilotage vers l'opérationnel sur le côté gauche de la pyramide : l'information devient de plus en plus précise en descendant,
- remonte dans le sens inverse sur le côté droit : l'information perd sa précision en remontant.

Étant donné que l'information est traitée différemment par les décideurs, qui peuvent par ailleurs interagir, nous proposons un cadre pour la dernière étape (l'étape du choix) du processus de prise de décision collaborative qui intègre ces différences et ces interactions (*cf.* fig. 5.7). Afin d'analyser des conflits relatifs à des décisions passées et anticiper des conflits futurs, en se fondant sur ce cadre, un indice est défini, qui mesure l'insatisfaction individuelle de chaque décideur à propos de la décision collaborative. L'agrégation de ces indices individuels donne un indice pour mesurer le risque d'invalidation d'une décision *a posteriori* (*cf.* section 5.5.6).

Ce processus, premièrement, met en évidence le cycle de vie de l'information dès sa génération jusqu'à sa consommation c'est-à-dire la décision elle-même. Deuxièmement, ce modèle permet de mesurer le risque d'invalidation de décision *a posteriori*. Troisièmement, ce modèle est utilisé comme une base pour collecter l'information sur les causes du retard *via* les entretiens avec des acteurs sur le terrain, ce qui est l'objet de la partie suivante de la thèse.

Étude des causes du retard

Nous avons effectué sept interviews approfondis avec trois chefs de projet et quatre décideurs en tant qu'acteurs majeurs du processus de la prise de décision. Figure 8.1 montre les axes thématiques de notre guide d'entretien. Ces entretiens ont durés au total 26 heures et nous ont permis de construire un compte rendu de 18 200 mots.

Nous avons identifié 252 facteurs clés qui influent la qualité et la rapidité des décisions collaboratives. Près de 50 % de ces facteurs sont liés au contexte : liés à la culture et à la gouvernance des sociétés. 30 % de ces facteurs sont liés aux sujets (aspect collaboratif) : liés aux attentes mutuelles des acteurs qui jouent des rôles différents dans le processus de décision. 20 % de ces facteurs sont liés à l'objet : liés à l'information à propos de l'état de projet (les propriétés de la molécule).

Parmi ces facteurs, nous avons identifié les facteurs saillants c'est-à-dire les plus cités par les interviewés. Le Tableau 8.2 montre les facteurs saillants les plus cités, qui sont triés par rapport à leurs fréquences totales (le nombre de fois où les différents aspects d'un facteur clé ont été cités) et leurs fréquences exactes (le nombre de fois où un facteur clé a été exactement cité de la même manière). Les résultats montrent que trois facteurs les plus cités en tant que causes du retard sont : la peur de l'incertitude, la peur de la hiérarchie et la difficulté des décisions d'arrêt. Nous constatons que quelques facteurs saillants n'ont été répétés que par une catégorie des acteurs. Par exemple, les deux facteurs suivants n'ont été répétés que par les décideurs : 1) le partage des convictions, et 2) la surcharge d'information lors de la présentation des résultats des tests par le chef de projet. Ce qui montre que, dans le cadre de ces exemples, les chefs de projet ne sont pas conscients des problèmes et des attentes des décideurs.

Ainsi, les facteurs controversés, sur lesquels les opinions des interviewés divergent, ont été identifiés (*cf.* section 8.2.3) :

- management de la situation non-urgente : la situation de la prise des décisions Go / No Go devrait être / ne devrait pas être considérée comme urgente. Dans le premier cas, le risque est de précipiter au lieu d'anticiper. Dans le deuxième cas, le risque est de repousser la décision,
- type de prise de décision : collégial / formel. Les décideurs avec une culture latine sont pour une prise de décision de façon collégiale et les décideurs avec une culture anglo-germanique sont pour une prise de décision de manière formelle,

– discussions de couloir : les discussions informelles en dehors du contexte formel des réunions sont jugées pénalisantes / avantageuses selon différents interviewés,
– nombre des décideurs : les différents interviewés sont pour un nombre limité / pas limité des décideurs dans le comité de pilotage,
– format de la présentation : les différents interviewés sont pour le format textuel (Word®)) / présentation (PPT®)) pour présenter les résultats des tests aux décideurs.

Les deux activités les plus citées du processus de la prise de décision sont la préparation et la présentation des résultats des tests effectués par les chefs de projet et la prise de décision collaborative effectuée par les décideurs.

Conclusions

Les projets R&D pharmaceutiques sont très longs, coûteux, et risqués. Tout au long de ces projets, une série de décisions Go / No Go doit être prise pour statuer sur la poursuite ou l'arrêt des projets en fonction des résultats obtenus. Ces résultats contiennent souvent des informations incomplètes, voire contradictoires, qui deviennent progressivement plus complètes et exactes lorsque les projets avancent. Or, l'avancement des projets dépend des décisions Go / No Go. Dans ce contexte et vu les enjeux importants des décisions Go / No Go, certains retards se manifestent parfois sous forme de suspension ou l'invalidation des décisions. Nous étudions le problème de retard dans la prise de décision collaborative face à l'incertitude, en situation non-urgente.

Dans la première partie de ce travail, nous soulignons les traits des projets de développement de nouveaux médicaments. Les difficultés et les complexités des décisions Go / No Go sont présentées et structurées. Ensuite, une étude bibliographique sur l'incertitude et l'indécision est présentée. Nous proposons une définition de l'incertitude adaptée au management de projet en prenant en compte le rôle du sujet, de l'objet et du contexte dans la génération et le traitement de l'incertitude.

Dans la deuxième partie, le processus de décisions Go / No Go est modélisé. Ce qui permet de visualiser et expliciter le cycle de vie d'information, d'illustrer comment l'information incertaine est traitée différemment par les différents décideurs et de calculer le risque de l'invalidation d'une décision collaborative *a posteriori*. Ce modèle nous sert de base pour mener une étude sur les causes du retard.

Dans la troisième partie, sept entretiens approfondis avec des acteurs majeurs de processus de décision sont réalisés : 3 chefs de projet et 4 décideurs. 252 facteurs clés qui influent le processus de décision sont identifiés, dont près de 50 % sont des facteurs liés au contexte. Les trois causes les plus citées sont : la peur de l'incertitude, la peur de la hiérarchie et la difficulté des décisions No Go. D'autres causes et pratiques abordées par les interviewés sont liées aux attentes mutuelles des chefs de projet et des décideurs et concernent majoritairement deux activités du processus de décision : la préparation et la présentation des résultats des tests effectués par les chefs de projet et la prise de décision collaborative effectuée par les décideurs. Si, à juste titre, beaucoup d'attention a été prêtée par le monde industriel à la façon d'effectuer les tests et de fournir les résultats, peu d'attention est portée à la façon dont on agrège, prépare et présente les résultats et dont on prend les décisions. En complément, afin de surmonter dans une large mesure le problème du retard et de l'invalidation des décisions collaboratives, cette thèse propose la formalisation du processus de prise de décision et l'identification de causes du retard et de pratiques efficientes associées aux activités de ce processus.

Appendices

A

Indecision

In this appendix, the results of our bibliographical study about indecision are presented. Three tables classify the causes of indecision according to subject(s), object or event, and context.

Table A.1: Causes of indecision related to the subject(s)

Individual causes:
- **personality of decision-makers**:
  - instability [Germeijs+ 2002] or not knowing what one wants [Frost+ 1993],
  - responsibility avoidance [Janis+ 1977] or divestment of responsibility [Bacanli 2006],
  - perfectionism [Frost+ 1993; Bacanli 2006], a maximizing tendency, especially in components of information search [Reed 1985; Schwartz+ 2002; Diab+ 2008],
  - tendency to consider the negative consequences of decision more harmful than negative consequences of inaction [Brooks 2011],
  - low self-esteem [Effert+ 1989],
  - low life satisfaction [Rassin+ 2005b],
  - low competitiveness [Effert+ 1989].
- **negative experiences of decision-makers**:
  - experience of difficulty [Chartrand+ 1990] or negative experience [Elaydi 2006]
- **needs and emotions of decision-makers**:
  - hypersensitivity to threat [Rassin+ 2005a],
  - inherent fear of (responsibility for) change [Rassin+ 2005a],
  - fear of mistakes and missing opportunities [Bacanli 2006],
  - doubt about the accuracy and completeness of the available information [Frost+ 1993],
  - doubt about the pertinence of the eventually / selected alternative [adapted from Reed 1985],
  - worry about the consequences of the decision (undesirable effects) [adapted from Germeijs+ 2002],
  - lack of clarity as to what the worry is about [Germeijs+ 2002],
  - post-decisional doubt / worry / regret about what would be lost (missing opportunities) [Frost+ 1993; Germeijs+ 2002; Bacanli 2006],
  - intolerance of uncertainty [Buhr+ 2002] or need for certainty [Bacanli 2006],
  - difficulty and panic under time pressure [Bacanli 2006].

Collaborative causes:
- ambiguity of the responsibility [Freeman 1999; Harris 2005]
- lone heroes and self-interest [Charan 2001],
- misfiring in personal interactions [Charan 2001],
- intimidation by the group dynamics of hierarchy [Charan 2001].

Table A.2: Causes of indecision related to the object / event and options

Causes related to information about the state of an object or the outcomes of some events:

- difficulty in searching for information [Bacanli 2006],
- limits on the quantity and quality of information [Paivandy 2008] such as:
  - absence: information is totally unavailable,
  - incompleteness: information is partially unavailable,
  - contradiction (incoherence): existence of paradoxical information,
  - noise: information is subject to random errors [Dubois+ 2001],
  - bias: information is subject to systemic errors [Dubois+ 2001],
  - imprecision: information is not exact,
  - volatility: information can change rapidly,
  - randomness: information is subject to "variability of observed repeatable natural phenomena" [Dubois+ 2010a],
  - ambiguity: existence of multiple and conflicting interpretations for the same information [Thiry 2002],
  - multidisciplinarity: information that concerns multiple domains. Multidisciplinarity is not a defect in itself, but may make information difficult to understand,
  - reliability: information whose source is not reliable,
  - redundancy: existence of several forms for the same information. Redundancy is not always a defect and may makes information explicit [Dubois+ 2001],
  - abundance: a great deal of information is available.
- information processing in an inefficient manner [Chang 2007].

Causes related to possible options:

- lack of option quality *i.e.* absence of a satisfactory option [Brooks 2011],
- lack of option clarity *i.e.* unclear or ambiguous options [Brooks 2011],
- conflict between equally attractive alternatives [Osipow+ 1976],
- option similarity, since decisions between similar options are difficult to make and also to justify to others [Brooks 2011], not accepting that the options are equally desirable [Neumann+ 1944],
- external barriers to preferred choices [Osipow+ 1976].

Table A.3: Causes of indecision related to context

Causes related to work environment:
- lack of intellectual honesty which harms open, honest, and decisive dialogue and decreases mutual trust [Charan 2001],
- lack of trust to protect oneself in an unsafe environment [Charan 2001],
- lack of conviction, meaning people "speak their lines woodenly" [Charan 2001],
- lack of emotional commitment, meaning people do not perform planned actions decisively [Charan 2001].

Causes related to leadership:
- strategic ambiguity [Denis+ 2011],
- "pluralistic settings characterized by diffuse power and divergent interests and conceptions" [Denis+ 2011],
- lack of candid dialogue and lack of emotional fortitude in leaders [Charan 2001],
- lack of follow-through [Charan 2001],
- constraints of formality [Charan 2001],
- lack of closure coupled with a lack of sanctions [Charan 2001].

Causes related to the status of decision and the process of decision-making:
- consideration of decision as "the prerogative of individuals - usually senior executives" [Davenport 2009],
- lack of clarity of the information, logic, and process used to make decisions [Davenport 2009].

Causes related to external environment:
- external barriers to preferred choices [Osipow+ 1976].

Causes related to time:
- time pressure [Bacanli 2006].

B

Interview grid

B.1 Decision

1. Are Go / No Go decisions *easy* to make?
2. During your career, have you often seen decisions deferred? If yes, what were the reasons?
3. After a number of times of decision postponements, what trigger decision-making (a new information which facilitates or reaching a consensus on the same information)?
4. Invalidation of decisions is common? If yes, what were the reasons? (decision recycling)
5. Is it difficult to stop a project? If so, what are these difficulties? Have you participated in a No Go decision? Could you share your experience?
6. Are the trace of decisions saved?
7. Do you have enough time to decide?
8. Is there a repeatable agenda for the Go / No Go decision meetings?
9. Does intuition play a role in decision-making?
10. What are the causes of delay in collaborative decision-making?
11. What are the efficient practices that facilitate collaborative decision-making?

B.2 Uncertainty

1. Are Go / No Go decisions made under uncertainty? If so, how frequent is it?
2. What are the sources of uncertainty?
3. What are its impacts?
4. How uncertainty is treated?

B.3 Information

1. On what factors are Go / No Go decisions based? (benefit-risk balance and what else?)

2. Does the presentation of the results influence the decision? If yes, what aspects and how?
3. What is the format of the results of the studies on which the decision is based? Is there a standard and repeatable format?
4. Do you have all the necessary information to make decisions?
5. Does the level of detail meet your expectations?
6. What do you think of the quantity of information presented? Is there any risk of information overload?
7. Do you think the results are presented objectively?
8. Is the steering committee specialized in different fields? Do you think that the presentation of the results is understandable to all the various specialists who contribute to decision-making or is there any problem with jargon? (jargon translator)
9. Do you have access to the results before the decision meeting or do you discover them during the meeting? If yes, how much time in advance? Do you have enough time to read?

B.4 Collaborative factors

1. What effect does it have that there are several people making the decision?
2. What are the mutual influences of individual and group?
3. What is the impact of hierarchical relationships on collaborative decisions?
4. Are some decision-makers' opinions overweighted ? (according to their specialities, for example)

B.5 Organizational culture

What are the impacts of the following elements on decision-making within an enterprise:

1. type of governance?
2. composition of the steering committee?
3. mode of information circulation?
4. explicit rules?
5. implicit rules?

B.6 Non-emergency of situations

1. Do you think there is an urgent need to decide? If so, what is the impact? If not, why are some decisions postponed?
2. How do you analyze this aspect?

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