Università Ca'Foscari Venezia

Master's Degree in Management

Final Thesis

Management Decision Making

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To my parents who allowed me to start,

Beatrice who has always believed in me and spurred me on the way,

my supervisor who trusted me and permitted me to finish.

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ABSTRACT

The current master thesis has as its main goal the complete analysis of the process of managerial decision making, from the bottom, talking about what is the process of decision making, to the top, going through some aspects such as the main concerns about the process, the generation of valid and useful data for the process, up to the actual decision and analysis and evaluation of the consequences.

There're also two others, less visible, goals. The first one, is to provide a coherent and unified vision about the topic, looking "outside the box". From my personal perspective, the literature about this topic is mostly fragmented and separated by the boundaries created by each field (e.g. mathematical, economical, managerial, social) and with its "excess of depth" it can't provide a summarized and an overall picture of the decision-making element. The last goal, is to provide the vast majority of decision-making models and examples to give to the reader a wider and holistic view about all the possible solutions together with its pros and cons for the decision-maker.

The process of decision making will be analyzed from three different points of view: the first one is the mathematical aspect, discussed mainly in the second chapter, the second one is socio-psychological aspect discussed in the third one, and finally the managerial aspect, discussed in the fourth.

In the first chapter, is given a short definition of what is the decision-making process with a brief representation and description of its main elements. Subsequently, the major group of obstacles that could limit and deviate the decision maker are defined, from the interpretation of the information gathered, to the description of the limits connected with the mankind and the enormous irrationality problem behind it.

In the second chapter is firstly defined the typical correlation between mathematical modeling and management, from the physical generation of a model, through its steps and rules, to its validation and application to the real world.

After the definition of the environment that surround the mathematical modelling it is given a representation of some basilar deterministic models, where the main characteristic, and also major assumption, is a total absence of uncertainty and risk. The sub-set of deterministic models discussed in this chapter are the Linear Programming (LP) models, with a focus onto its main variant, known as Simplex method. After the end of discussion about the theory surrounding the deterministic models, the focus is shifted towards three concrete problem examples: transportation, network, and queuing.

Subsequently, the focus is moved towards the discussion of a more realistic scenario in which uncertainty and risk are taken into consideration. Here, some major models and their implications are defined.

Lastly, the last paragraph is dedicated to a particular branch of the managerial mathematical modelling, known as the Multi-Criteria Decision Making (MCDM). The objective of these types of models is to translate multiple subjective and/or partially objective evaluations into a critical and objective model, that can be used to make more valid and reliable decisions.

In the third chapter, the entire decision process is analyzed, starting from the beginning or problem framing, until the end or the decision implementation and its monitoring, following the complex problem thinking model.

The second paragraph, instead, shifts the attention towards the discussion about the post-decision analysis. Here, the effect of the decision is discussed and evaluated from the human perspective, then a synthetical model for the evaluation of failures is given.

Subsequently, the team argument is discussed, starting form a discussion of its lifecycle, proceeding towards the definition of the possible type of power and power style typical for every temperament, and the different decision-making approaches. As regards the team topic, the last sub-chapter shifts the discussion on the possible problems and conflicts that can be encountered, such as self-oriented roles, groupthink effect, and different conflict styles connected to each temperament.

Finally, the last paragraph has, as a main purpose, the discussion of forecasting models and consequently of subjective probability assessment associated with the use of experts.

In the fourth chapter a series of data gathering instruments related with the decision aspect of the management control argument are discussed.

In the first paragraph is briefly discussed the importance and the value of having quality in data and information, defining the different types of data and their typical lifecycle.

In the second paragraph different instruments dedicated with the feedforward control are discussed, starting from the present, moving towards short-term and long-term decision making, until the definition of the roles of standards, estimates and budgeting in the decision process.

In the third paragraph are discussed the feedback aspect of the management control and the role of performance measurement instruments with an internal and external perspective to the firm.

Lastly, the fourth and final paragraph shift the entire discussion from the monetary perspective to the value one talking about the relations between key management processes and value-based thinking.

CHAPTER 1

An introduction on the science of managerial decision-making

1.1. Introduction

"A good decision is the end result of carefully selecting a preferred course of action after studying what might happen were a variety of alternatives chosen."[1] In this manner, Goulb Andrew L. defines what is a good decision. Note that the emphasis on this sentence is placed on the process of making a decision, and not on the decision itself.

In the past years, a lot of different scholars, with different ideologies, have analyzed and deconstructed the problem to define actors, processes and solutions that concur to the decision-making problem. Psychology, Sociology, Mathematics, Economics and Management are all involved, and these subjects cooperate together with the aim of finding the best possible path towards a decision.

The reason why the process of decision making is so important has to be addressed to the way it shapes and gives substance to the ecosystem that surround an effective decision, it defines what we know and what we don't know, it defines the element of risk and uncertainty involved in the decision as well as the consequences and alternatives to that decision.

This leads to a simple but also important question: "why some decisions are hard to make

[1] Goulb Andrew L., Decision Analysis: an integrated approach, John Wiley & Sons, Inc., 1997, pg. 2

and some others are not". To answer at this question is useful to bring a case study as an example, adapted from Clemen Robert T., Making Hard Decision.

Gypsy moth and the ODA

> "In the winter of 1985, the ODA (Oregon Department of Agriculture) grappled with the problem of gypsy moth infestation in Lane Country in western Oregon. Forest industry representatives argued strongly for an aggressive eradication campaign using potent chemical insecticides. The ODA instead proposed a plan that involved spraying most of the affected area with BT (*Bacillus thuringiensis*), a bacterial insecticide known to be (1) target-specific (that is, it does little damage to organism other than moths), (2) ecologically safe, and (3) reasonably effective. As well as using BT, the ODA proposed spraying three smaller area near the city of Eugene with the chemical spray Orthene. Although Orthene was registered as an acceptable insecticide for home and garden use, there was some doubt as to its ultimate ecological effects as well as its danger to humans. Forestry officials argued that the chemicals insecticide was more potent than BT and was necessary to ensure eradication in the most heavily infected areas. Environmentalists argued that the potential danger from the chemical spray was too great to warrant its use. Some individuals argued that spraying would not help because the infestation already was to advanced that no program would be successful. Others argued that an aggressive spray program could solve the problem once and for all, but only if done immediately. "[2]

Through a careful analysis of the problem faced by the ODA, we can underline the various elements that makes this decision so hard to take. The first problem encountered lies in the complexity of the decision. As a matter of fact, in the previous scenario, the complexity in the problem encountered lies in the economic and environmental impact of any pesticide control

[2] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 1

program, the complexity of the various groups involved from a value point of view, amongst the most important ones, as well as many other secondary ones.

The second factor that can make a decision hard, is the uncertainty itself. In our case, it can be represented by the intrinsic uncertainty about whether the pesticide control instrument is effective or not, to which extent, and also by its uncertainty on the environmental and health side.

The third factor of difficulty can be represented by a multiple objective situation, where a step toward one objective can or should influence the position of another one. In this case, it is necessary to evaluate the trade-off between cost and benefit for each component of the decision, in the situation highlighted in the case study is represented by the trade-off between effectiveness and environmental/heath damage in the use of Orthene as pesticide.

A problem might be difficult also when two different perspectives lead to two different conclusions. From the ODA case, we can see the perspective of different groups, everyone with its way of thinking and their own different solutions, from the forestry officials perspective, unbalanced toward a more effective but less environmentally friendly solution, to the opposite perspective, from the environmentalists point of view, which prefers the use of less aggressive pesticides.

"Our decision makers are not economic automations; they make mistakes, have remorse, suffer anxieties, and cannot make up their minds. […] decision making, even for an individual, is an act of compromise among different selves."[3] As it is intuitable by the quoted sentence, the last element is related to the human being with all its behaviors and biases, such as anxiety, ideologies, and also with the need for an internal consensus inside the figure of the decision-maker. In the previous case study, this is represented by the fact that the decision maker (ODA) is composed by a group of people each one with different bias and ideology. In this group, someone will have the burden to generate a valid solution to the problem and some others will have the burden to approve or discard that solution, knowing that these groups are made by different people, each one with a different way of thinking.

[3] Bell David E., Riaffa Howard, Tversky Amos, Decision Making: Descriptive, normative and prescriptive interactions, Cambridge University Press, 1988, pg. 9

It is obvious that the decision-making process it is not always a straight forward action, the complexity of the problem may depend on the presence or on the absence of a series of factors which may be external or even internal to the picture of the decision-maker.

1.2. Element compositions of decision-making problems

To begin this voyage toward the world of decision-making is useful to make a step backward and define the main elements that surround a decision. The next classification about the composition of decision problems is adapted from the book Clemen Robert T., Making Hard Decision [4].

It is therefore possible to outline the four different elements that shape a decision context:

- Values and objectives;
- Decisions to make;
- Uncertain events;
- Consequences.

Values and objectives

First of all, concerning the first point in the list above, it is necessary to address a definition of the two elements: values and objectives. Values can be defined as a set of principles or standards that shape our behavior, one's judgement of what is important in life, what matter to us. An objective can be defined as what you want to achieve, a goal.

Values can be represented as the start of our decision making, on the other hand, objectives are representative of the end of that decision, but not the end of the overall problem-solving process because it is always necessary to bear in mind that there are always a series of consequences for every decision.

[4] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 19-34

In the analysis of the first bullet in the list it is also necessary to understand the importance of the decision context that surround values and objectives. "Values and decision context go hand in hand. On one hand, it is worthwhile to think about your objectives in advance to be prepared for decisions when they arise or so that you can identify new decision opportunities that you might not have thought about before. On the other hand, every decision situation involves a specific context, and that context determines what objectives needs to be considered."[5]

Decisions to make

The second element considerate by the author is the problem of what is the best decision to make, for every scenario there can be a different number of decisions to make before reaching the objective, from zero to a finite but very large number. Note that the scenario with zero possible choice is very peculiar, there is not a path to be undertaken, it is just a passive scenario for the decision-maker where the only possible solution is to wait and see the consequence of a particular event.

In all the others decision scenarios there are some critical steps that have to be made. First of all, it is necessary to identify the immediate decision to make, giving a specific and congruent order to the sequence of further decisions. The second step, is to identify the crucial decision and consequently generate a valid number of possible alternatives to reach the same group of objectives.

Note that the best choice is not always to take action, the decision-maker can also choose to take no action or postpone the decision to have the time to obtain more information with the purpose of making a better, and less risky, choice.

Not every objective can be reached with only one decision, in these scenarios is useful to adopt a sequential decision procedure, where the group of decisions is ordered chronologically from the most urgent decision to the less urgent one. There is also the possibility that the future choice depends upon the previous one, generating a dynamic decision situation.

[5] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 22

Uncertain events

Uncertainty is a fundamental element in every decision, it defines how much we know about the present and future of a specific event, it is also important to give a definition to what is an outcome, which can be defined as the group of possible results after an uncertain event becomes certain.

Not every uncertain event is important in processing a decision, it is therefore necessary to consider only the specific group of uncertain events that can or may have an influence on one or more objectives.

In a sequential decision scenario, that will be treated more deeply in the future chapters, it is fundamental to evaluate what is the group of uncertain events connected to every decision step and consequently define and resolve for each step the critical one. Since it is likely that the next decision depends on the outcome of a series of uncertain events, the impossibility to solve these critical events can deviate the decision-maker from its objective or even block the decision sequence.

Consequences

In this contest, it is possible to define the last bullet of the previous list, the consequences, as the final result following the resolution of every uncertain event and the last decision. With all these preliminary definitions and contexts given, it is possible to connect values to objectives and also quantify how much the result deviates from the initial objectives list.

One of the last components to define is planning horizon that can be considered as the period of time after the last decision, or the duration of the consequence element. Time is one of the fundamental components of every decision as well as an obstacle to that decision.

In the context of consequence evaluation, the time component is relevant for two different reason, firstly it is relevant to define how much time occurs between the begin of the procedure itself and the start of the consequences, secondly, and more importantly, a certain interval of time is set and within that interval the consequences of our decisions will be analyzed.

Lastly, the consequence element needs a metric unit to be evaluated, usually, for its simplicity on comparison and allocation is used a monetary metric, but nothing prevents the decision-maker to use non-monetary metrics in the evaluation process, obviously following a careful consideration of its pros and cons.

The next figure is a schematic representation of the previous elements in a sequential decision scenario:

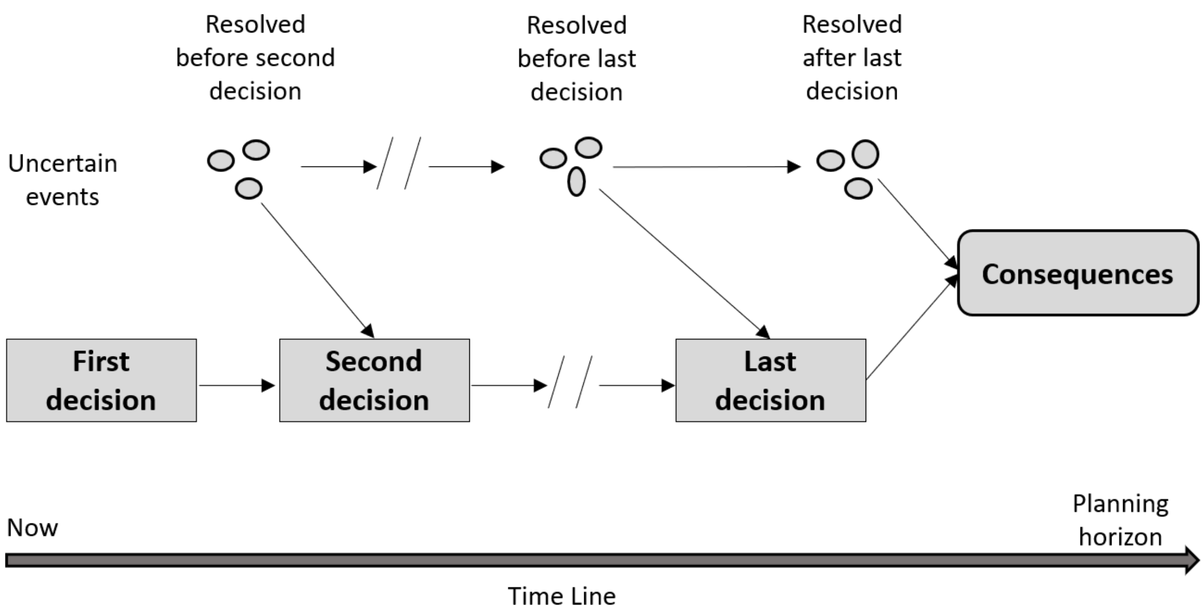

Figure 1 Scheme of decisions elements [6]

1.3. Main obstacles to decision-making

Decision-making, in most of the daily decisions, can be considered as a linear, routinely and flowing process, without a consistent presence of obstacles along the path. But this is not always the case. In some particular scenarios, where the consequences of our decisions are particularly relevant, obstacles can represent a huge limitation in the ability to take a good decision.

[6] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 27, Figure 2.4

In this paragraph will be discussed a series of the main categories of obstacles for the decision maker such as:

- Information and data;
- Time;
- Objectives;
- Risk;
- Irrationality.

"[…] when the environment is sufficiently stable and the choice situation is familiar, rationality can be a predictive tool. […] we may not reach the same conclusion when the environment is not a natural but a social one."[7]

To understand the context is useful, as a first step, to give a concise representation of the rational approach to decision-making and its limitations. The next Figure is a graphical representation of the analytic steps of the rational decision model adapted from Goulb Andrew L., Decision Analysis.

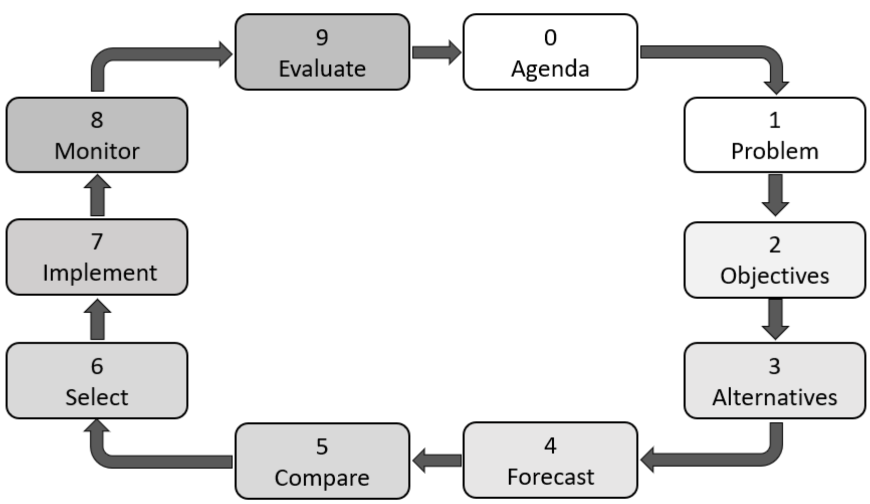

Figure 2 The ten steps of the Rational model[8]

[7] Bicchieri Cristina, Rationality and Coordination: Cambridge studies in probability induction, and decision theory, Cambridge University Press, 1993, pg. 14
[8] Goulb Andrew L., Decision Analysis: an integrated approach, John Wiley & Sons, Inc., 1997, pg. 9

Note that the author of this representation has added some more intermediate step in the process in comparison of the traditional rational model to decision-making.

0 Agenda – The step zero of this specific decision process is to set an agenda in which is determined what problems will be analyzed and studied in the process. This can be considered as a "pre-process" step of the entire cycle as its scope is only to prepare the foundations of the real process.

1 Problem – This is a pretty straightforward step and consist in the definition of the problem that we want to fix.

2 Objectives – Once a problem is identified is necessary to define the objective, element already defined in the previous paragraph.

3 Alternatives – This step consists into the identification of the possible solution to the problem that can possibly lead to one or more objectives.

4 Forecast – The forecasting step consists in a representation of the future for each alternative.

5 Compare – Through the use of a scorecard (comparison instrument that will be discussed in the next chapters) every forecast is compared.

6 Select – In this step the forecast with the highest score in the scorecard, or the forecast that hit the highest score for the most relevant between the objectives, is chosen.

7 Implement – After the selection step the previous best alternative is implemented and executed, is possible to define this as the point of no return where an idea is translated in action.

8 Monitor – In the monitor step the previous implementation is monitored to see if there is a failure in the alternative chosen. This can happen for different reasons that can be classified as:

- Theoretical failure (a faulty idea in the first place);
- Chance failure (chance of unpredicted behavior in the events);
- Implementation failure (a failure in the implementation of the idea).

9 Evaluate – This last step consists in the evaluation of how much the final result of the monitoring step match with the objective, and how much the problem is resolved. If the result of this step does not match the requirement to consider the original problem solved the entire process should be repeated.

At first sight this methodology seems a rational, good, precise and objective process from the beginning to the end, but with a second and more targeted analysis is possible to see some "crack" inside due to a series of relevant obstacles like time, lack of information and irrationality of the human being, that will be discussed in the next five sub-paragraphs.

Note that there's no precise boundaries between these five different focal points but rather a series of shades with different intensities between them.

1.3.1. Information and data

In this paragraph the information element will be discussed mostly under a rational point of view because the irrational element (such as confirmation bias) is part of the fifth sub-paragraph.

The first sub-group, but not for relevance, of obstacles outlines a series of problems correlated with the data element, and consequently with the information that will be extracted from that specified data.

Firstly, it is necessary to define an Information Set (IS) also known as Information Structure "Information or more generally the information set or structure refers to the knowledge about the environment, which help or hinder the DM (Decision-Maker) in arriving at the most satisfactory decision: it may refer also to the lack of knowledge of the parameters of the DM's payoff function itself which may be partially subjective in character."[9]

The next series of distinctions have the purpose to underline the complexity of the information and why can be considered an obstacle for the decision maker.

Prior vs. posterior IS

The basic difference between them is that in the prior IS case, the decision-maker starts with some previous and subjective beliefs before the decision process, vice versa in the posterior IS case.

Perfect vs. imperfect IS

The imperfectness of information structure is referred to partial knowledge on other actors or on the conditions of the environment that surround the decision-process.

Complete vs. incomplete IS

The degree of completeness is referred to the state of the environment in which the variables of the problem are defined. In control theory, for example, a complete state information means the minimization of the loss function in the variables that defines the environment.

Symmetrical vs. asymmetrical IS

Asymmetry is referred as "the form of distribution of the stochastic component in the environment (e.g., normally distributed or not), or the sensitivity of the decision rule to stochastic perturbations in data or the environment"[10]

[9] Sengupta Jati K., Optimal Decisions under Uncertainty: methods, models and management, Springer-Verlag, 1985, pg. 121.
[10] Sengupta Jati K., Optimal Decisions under Uncertainty: methods, models and management, Springer-Verlag, 1985, pg. 122.

Homogeneous vs. heterogeneous IS

Heterogeneous is referred to the different structure that an information can assume, depending on the origin source of that information, an intuitive example can be represented by the same information given by two different actors that can take different facets.

Dual vs. nondual IS

The duality factor is referred to the learning effect that is sited inside the elaboration of IS in the scenario of sequential information.

Passive vs active IS

Also known in the stochastic approach as the wait-and-see, passive information structure is referred to a situation where the actors around the decision-maker are non-interactive and consequently they don’t use their information to enhance their payoff.

As it is obvious form the previous series of distinctions, information can be a huge obstacle because it is a mutable and non-static element but under rather dynamic.

In connection with the ten steps of rational model discussed in the previous paragraph it is possible to see, under the information point of view, where its limit is situated. A clear example can be a situation in which information are partially imperfect and/or incomplete. The rational model is effective and efficient only under strong assumptions or in particular situations and in this, not so unrealistic, scenario can increase exponentially the degree of failure in some step of the process.

1.3.2. Time

A second category of obstacles for the decision-maker is the time element. Time can be a huge problem because it is limited, every decision process has a maximum period of time in which a certain decision can be taken, and after that there’s no more room for intervention to fix the problem and reach any of the objectives. Note also that, in some particular scenarios, to not take any decision is technically a decision, but this possibility will not be discussed in the next chapters, as usually this don't happen in a managerial environment.

Time can be seen as limited under two different aspects, the first one, is a natural time limit, as an example to the managerial scenario this could happen due to maximum work hour per day (closely related to our circadian rhythms). In relation to the rational model previously discussed the limit of that method under this aspect is greatly defined in the next quote "It must be emphasized that the application of the rational model can be time consuming. The following case study looks at two attempts to create a rational procedure for developing the budget for the U.S. government. It appears that the amount of time spent on budget analysis ended up restricting the amount of time that individuals had to do their jobs. […] Evidence suggest that many decision makers tend to follow a rational procedure, but that they reduce the difficulty of the analysis by cutting corners."[11]

The second possibility for a limitation under the time variable is an anthropic type of limit, more common than the other one in a managerial environment. This type of limitation is referred to the presence of deadlines set by humans.

The next quote is a possible solution for the time obstacle in the rational model and can help to the understanding of this second type of limit. "A busy decision analyst should establish a reasonable amount of time for the study of each problem and tailor the analysis to meet the deadlines as close as possible. Given time constraints, not all analyses can be totally comprehensive."[12] In this quote it is possible to note that the solution given is only a compromise and it is also time limited because the amount of time available is strictly correlated with the amount of information available, and this, as mentioned in the previous sub-paragraph, leads to a certain level of uncertainty.

[11] Goulb Andrew L., Decision Analysis: an integrated approach, John Wiley & Sons, Inc., 1997, pg. 13
[12] Goulb Andrew L., Decision Analysis: an integrated approach, John Wiley & Sons, Inc., 1997, pg. 14

1.3.3. Objectives

Objectives, as defined in paragraph 1.2., are goals that we want to achieve. They can be a problem for the decision-maker for a series of reasons. First of all, it is necessary to outline two situations, the first one is decision-making with only one objective, the second one, intuitively, is multi-objective decision-making.

As regard the mono-objective decision-making, the objective element generally is not considerable as an obstacle with only one exception, if there's some sort of impossibility in the delineation and structuration of the decision process. This can happen in some peculiar situations where the problem is well defined but the decision-maker, for internal or external reason, can't clearly define the goals. Note that for internal reason is intended some sort of block due to reasons inside the thinking process of the decision-maker (he/she don't know what he/she want), for external reason is intended some sort of block due to reason correlated with the environment that surround the decision process (the definition of the objective is attributed to another actor).

The previous condition can be associated also with the multi-objective decision-making but this type of decisions carry also two other problems: conflicts within main and secondary objectives and side effects associated with reaching a goal.

As regard the conflicts problem, it can happen when reaching of one objective preclude partially or totally the reaching of another one. An effective solution to this problem, that will be discussed in depth in the next chapters, is to define a scale of importance for the objectives and consequently reaching one objective at time, from the main to the less important, in this manner it is possible to obtain a good result.

The problem of side effect instead is referred to the group of hidden, and usually unwanted, effect of reaching a goal. To help a better understanding, this problem can be considered conceptually similar to the problem of positive and negative externality in macroeconomy (problem that won't be discussed in this thesis). In this case the only possible solution is, where possible, to correct the side effect with specific actions.

1.3.4. Risk

Risk, as defined in the classical decision theory, "[…] is most commonly conceived of as reflecting variation in the distribution of possible outcomes, their likelihoods, and their subjective values. Risk is measured either by nonlinearities in the revealed utility of money or by the variance of the probability distribution of possible gains and losses associated with a particular alternative" [13]. From an economical point of view risk can be considered as an obstacle to the extent in which his distribution is balanced toward unwanted outcomes, not a critical obstacle if we take for grant the constants that shapes the environment of decision theory.

But, as is possible to read in the next pages of that book, "[…] The managers who participated in this study saw risk in ways that appear to be different from the definition of risk in decision theory. They showed very little inclination to equate the risk of an alternative with the variance of the probability distribution of outcomes that might follow its choice" [14]. In the previous quote is possible to see the risk element under a managerial point of view and consequently it is also possible to understand why its considerable as a real obstacle for the decision maker.

The next representation of the risk element from a managerial point of view is adapted from an empirical study of the relations between managers and risk from the book: Shapira Zur, Risk Taking.

It is therefore possible to outline the four different aspects that characterize the way in which managers consider risk:

- Huge consideration of downside risk;
- Greater attention to magnitude of risk;
- Sharp definition between risk taking and gambling;
- Little desire to reduce risk to a single quantifiable construct.

[13] Shapira Zur, Risk Taking: a managerial perspective, Russel Sage Foundation, 1995, pg. 22
[14] Shapira Zur, Risk Taking: a managerial perspective, Russel Sage Foundation, 1995, pg. 43

Huge consideration of downside risk

As regard this statement, managers tend to give more importance to the downside outcomes of a risky choice rather than to the upside outcomes. Consequently, a risky choice is more associated with the negative element.

Greater attention to magnitude of risk

This statement is focused around the idea that risk is primarily seen as a magnitude rather than a probability concept, this leads the decision-maker to opt-out from a risky decision if the magnitude of the worst outcome of that decision is higher than the maximum acceptable loss, not taking into account the actual probability for the happening of that event.

Sharp definition between risk taking and gambling

Managers consider gambling as a totally different concept from risk taking, the latter is considered more skill based and have the necessity of a higher degree of control for the decision-maker.

The next graph is adapted from the book: Shapira Zur, Risk Taking, and represent the data from the empirical study for the correlation among risk taking, gambling, skills and control.

SAMPLE RESPONSE	Government Employees (N = 61)	State-owned Corporations (N = 98)	Financial Institution (N = 85)	Leading Executive Program (N = 66)
Risk taking related to gambling*	1.85	1.94	1.79	2.56
Control in risk taking (Gambling)**	3.87 (2.42)	3.89 (1.96)	3.78 (2.68)	3.79 (2.14)
Use of skills in risk taking (Gambling)***	4.61 (2.08)	4.29 (2.30)	4.60 (2.93)	4.27 (2.67)

Notes: Numbers in parentheses refer to questions about gambling.

*	1	2	3	4	5
	No relation	Some relation	Relation	Strong relation	Virtually the same

**	1	2	3	4	5
	Absolutely no Control	No Control	Neither Control Nor no Control	Control	Absolute Control

***	1	2	3	4	5
	Always luck	Mainly luck	Neither Skill nor luck	Mainly use of Skills	Considerable use of Skills

Table 1 Mean response of managers in different organizations on the relations among risk, gambling, control and skills [15]

Little desire to reduce risk to a single quantifiable construct

Risk is seen from the managers as a multidimensional element rather that a single quantifiable construct, because the latter can't fully represent or be enough helpful to the decision process.

"It appears that the process of thinking is sequential and comprises the following steps: First, edit the distribution of outcomes into a few discrete alternatives. Examine the worst possible outcomes. If it is not tolerable, drop that alternative. If it is tolerable, attend to the positive outcomes and search for one that clearly dominates the bad outcomes. Such a process is different from choice that is based on calculation of expected values and variances." [16]

[15] Shapira Zur, Risk Taking: a managerial perspective, Russel Sage Foundation, 1995, pg. 50
[16] Shapira Zur, Risk Taking: a managerial perspective, Russel Sage Foundation, 1995, pg. 52

In conclusion, risk can be considered as an obstacle for the decision-maker only in correlation with its disposition to introduce some sort of distortions on the evaluation of the risk element of an alternative in the decision process.

1.3.5. Mankind

The last typology of obstacles discussed in this paragraph consists in the representation of the decision-maker as a human, with its bias, irrationality, behavior, etc.

From the sociological, psychological and medical field is possible to outline an almost infinite list of "problems" that can affect the decision side from a human perspective, and for every one of them is also possible to write an entire thesis on. Consequently, the purpose of this sub-paragraph is to give a brief idea of the most common categories of mankind problems that can affect decisions, without going too deep in the argument.

"In theory, decision-making is simple. A problem emerges. The goal is defined and the possible options for achieving it and solving the problem identified. These options are then analyzed and the one that seems most effective is selected. Powerful mathematical tools are available to facilitate the task. Yet if it is so simple, why do business keep getting it wrong?"[17]

Mankind can be considered the most relevant and complicate obstacle, relevant because if we not consider the possibility of a mechanical decision maker driven by an artificial intelligence every decision maker is human, and complicate, because, as a human, it has a series of intrinsic limitations that can influence, to some extent or even totally, every other obstacle element discussed previously, possibly making an easy decision a hard one.

For this topic, can be outlined the next list of obstacle categories:

- Overconfidence;
- Confirmation;
- Anchoring;

[17] Drummond Helga, Guide to Decision Making: getting it more right than wrong, The Economist Newspaper Ltd., 2012, pg. 1

- Analogy;
- Availability;
- Vividness;
- Instant response;
- Expectation.

Note that in this sub-paragraph will not be discussed the problems related to group decision-making as it will be discussed in the next chapters.

Overconfidence effect

The overconfidence problem, as the name suggest, is referred to a situation where the high level of confidence from the decision-maker in a particular subject leads to wrong or bad decisions. This could happen due to various factors such as a series of previous right decision or a high experience in that type of decisions, leading the decision-maker to overestimate their ability and under evaluate uncertainty, risk and possible bad outcomes.

Confirmation effect

Confirmation effect is referred to the tendency of the decision-maker to pay more attention to the information that confirms its ideas rather than the information that contradict it.

Anchoring effect

Anchoring effect is that particular decision-making limitation that consist in the influence of the environment. When the decision-maker needs, as an example, to guess or forecast a value, it unconsciously picks the stimulus provided by the environment (such as date, list of numbers in a sheet etc.) and make the guess or forecast only adjusting that value to reach a “plausible” value.

Analogy effect

Analogy effect happens when the decision-maker applies the same solution to two specifically different, but generally similar, problems, leading to the possibility of missing important information and differences between the two.

Availability effect

This particular effect consists in the fact that, for the decision-maker, a recent event has a greater impact and importance than an older one. This happen because, with time, human memory has the tendency to erase older memories and keep the fresh ones.

Vividness effect

Vividness effect represent the tendency of the human mind to remember bright images and alluring ones. As an example, this leads to remember more easily people that dress white rather people that dress black or with dark colors, to remember more easily events that appear at the news such as a plane that have crashed. This effect is considered a limit because, as it is possible to guess from the plane crash example, leads the decision-makers to think that an event is more statistically probable than what really is, and consequently misleading their decisions.

Instant-response effect

The instant-response effect refers to "decisions made on the spur of the moment, based purely on emotional reaction. The result of such hasty decision-making may not be happy because mood affects our ability to exercise objective judgement" [18] As it is intuitable, this particular effect is totally based on the emotional situation of the decision-maker, leading to unprecise or random decisions, moreover this effect could also influence the other, previously defined, effects, as an example in the case of overconfidence where an extreme mood can give it a boost, increasing the possibility to take wrong decisions.

Expectation effect

The last element in this list is the expectation effect, this particular effect represents the tendency of the decision-maker to, once it makes an explanation for a particular event, to adapt and rationalize every new information about it only to fit and justify its previous explanation, leading it to obscure the reality and consequently the possibility to have given a wrong explanation.

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[18] Drummond Helga, Guide to Decision Making: getting it more right than wrong, The Economist Newspaper Ltd., 2012, pg. 24

As said before, this particular type of obstacles can influence every other obstacle previously defined. In the information limit element, form the subjective side, the human irrationality derived from the combination of the previous list of effects can leads to deviated and misrepresentative information. The same goes for the objective and risk limit, where human limitations leads to irrational evaluations of them.

In correlation with the ten steps of the rational model, over the influence on the other limitation categories, human irrationality is an obstacle because it limits the ability of the decision-maker to look objectively at the problem that need to be resolved and consequently limits also the ability to use correctly logic in combination with mathematical and statistical instruments, making hard to deduce the best course of actions to solve that particular problem.

CHAPTER 2

A mathematical approach

Mathematics is the fundamental structure of everything. In this chapter will be discussed some of the most common mathematical models able to help the decision-maker in the decision-making process.

The next paragraphs are divided in three main different categories, the first one is deterministic models, useful in the representation of the reality in scenarios where there is no uncertainty, the second category comprehend the most common models and procedures in scenarios where uncertainty cannot be neglected, the third, and last, category discuss about Multi-Attribute Decision Analysis (MCDA) and its implications.

Note that usually, in a managerial scenario, these mathematical models can help to give solutions only for a portion of a particular problem. The human element makes almost impossible to generate a unified theory for all the decision problems.

2.1. Mathematics in a managerial context

Before start with the analysis of the three previous categories it is useful to define the managerial context for the applications of mathematical models.

Usually in a managerial context, unless the presence of particular skills for the manager, the union of mathematics and management is made by a subject called modeler. The scope of a modeler is to define what part of the problem can be mathematically modelled, and generate a model that can solve that particular fraction of the entire problem.

Before begin to describe the five stages of mathematical modeling, it is necessary to define the concept of a variable for a modeler. For a modeler there are two type of variables:

- Input;
- Calculated.

Input variables

An input variable is a particular type of variable that is exogenous from the modeler's environment, where, for exogenous, is intended "having an external cause or origin". These variables are taken by the modeler directly from the modellable portion of the problem in the managerial environment.

Calculated variables

A calculated variable is, vice versa, a particular type of variable that is endogenous from the modeler's environment, where, for endogenous, is intended "having an internal cause or origin". In detail, this type of variable is generated by the modeler starting from a series of input variables.

An input variable can be successively classified in three more sub-categories:

- Constants;
- Coefficients;
- Parameters.

Constant variables

"The term 'variables' has been used (rather than variables and constants) since it is both convenient and illuminating to start by considering all factors to be variable. This is not so draft as might appear since it fits in with the old saying that everything is variable in the long run." [19]

[19] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 52.

Once made the previous disclaimer, a constant variable is an input variable that is considered fixed in time in the elaboration of the information set.

Coefficient variables

"[…] these are variables whose values have been derived from past experience; usually this means that they have been statistically derived from data, but they could have been decided upon subjectively possibly simply by hunch." [20] Intuitively, as a consequence of the previous definition, it is possible that a coefficient variable is comprehensive of some sort of subjective errors due to its particular nature.

Parameter variables

A parameter is a type of input variables that is temporally held fixed by the modeler, as a consequence of it, it is considerable as a particular constant variable.

The next figure summarizes the previous series of definitions.

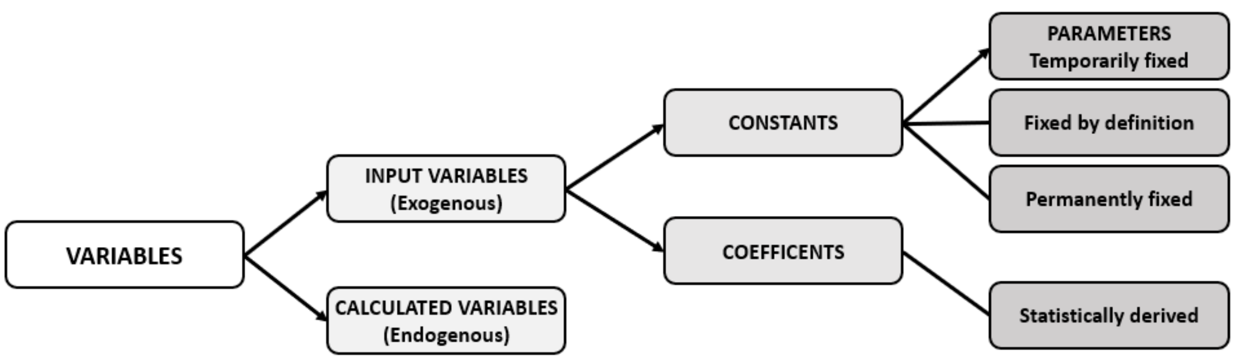


Figure 3 graphical summary of variables [21]

[20] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 53.
[21] Partially adapted from: Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 54.

2.1.1. Steps of mathematical modelling

The next representation of the stages for mathematical modelling in a managerial scenario is adapted from: Finlay Pauln N., Mathematical Modelling in Business Decision-Making.

From a modeler's perspective the process of mathematical modelling can be defined as represented in the next figure.

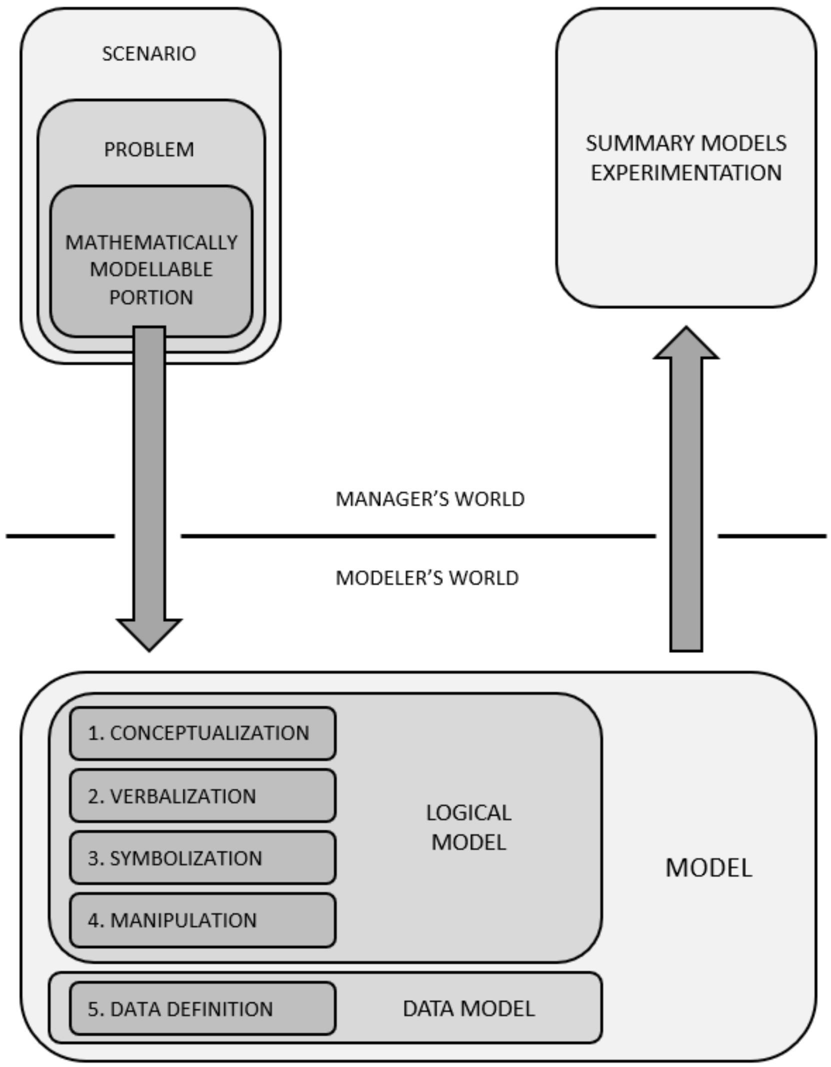


Figure 4 The process and methodology of mathematical modelling [22]

[22] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 49.

After the definition and description of what is a variable and how is classified, it is possible to discuss the figure four. As it is possible to note, the generation of a model is composed by five different stages:

- Conceptualization;
- Verbalization;
- Symbolization;
- Manipulation;
- Data definition.

The first four stages have the task to define the logical model, instead the fifth one defines the data model. Finally, the union of the previous two models generate the final model that is successively used from the manager to compose a better decision to the main problem.

Stage 1 - Conceptualization

The first stage in the generation of a mathematical model is the conceptualization. In this critical stage the modeler converts the portion of the managerial problem, empathizing precision. To complete this step, the modeler needs to "look" in three different direction:

- Backward;
- Sideward;
- Forward.

Backward – "First the modeler will be using a scenario of the system under investigation to look backwards and link with the manager to ensure that the problem as defined by the manager is indeed a sensible definition of the problem."[23]

In the previous quote note the separation of the decision-maker in two different subject and the consequent control process between them.

[23] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 56.

Sideward – Second, the modeler looks sideward to see if this particular problem fit in already defined and solved problems, for which a model or technique already exists, reducing the amount of time needed to solve the problem.

Forward – Third, the modeler has to look forward on how the model will be used by the manager, from the information presented, to the method of interaction with the manager.

In this stage start the structuration of the logical model that, in combination with the data model, generate the final model for the manager.

Stage 2 - Verbalization

In the second stage the modeler has the task to connect all the variables in a “verbal” manner. More precisely the modeler specifies the relation between variables in an accurate and precise series of statement in English (in the majority of the scenarios). Note that for verbal it is not intended spoken but not-symbolic.

Stage 3 - Symbolization

In the third stage the modeler converts the previous series of “verbal” statement in a symbolic language, where at each variable is assigned a unique symbol. This need to be done to permit at the variables to be manipulated by mathematics.

In this stage it is also necessary to state the units used for each variable with the purpose to avoid errors.

Stage 4 - Manipulation

The fourth stage is constructed around the manipulation of the symbolic relations previously created with the use of functions. This can “extract’ values from the starting variables producing benefits.

At the end of this stage the logical model is complete and it is necessary to proceed with the definition of the data model.

Stage 5 - Data definition

In the fifth, and last stage, the input variables are obtained from the problem environment. "This indicates the major reason why data definition should be left until the latter stages of model building; the logic situation is needed to define the data needed and its precision, because obtaining data, especially precise data, cost time and money." [24]

In this stage it is also useful to define the two dimensions of a data model:

- Precision;
- Accuracy.

Precision – For precision is intended a measure of the level of uncertainty in a set of data. Less uncertainty equals to more precise data set.

Accuracy – For accuracy is intended a measure of the systematic bias in a set of data. High accuracy means that the data collected are more focused in one point.

This stage represents the conclusion of the mathematical model, after this stage the model created needs to be validated in order to be used by the manager, avoiding fatal errors.

2.1.2. Validation of a mathematical model

The validation of the mathematical model generated, as said in the previous sub-paragraph, is a fundamental process that have to be made to avoid sub-optimal decisions.

There are two types of validation that need to be done on the logical model:

- Analytical validation;
- Synoptic validation.

[24] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 63.

Analytical validation

The analytical validation consists in the check of all the assumptions made, and also in the evaluation of the consistency of the dimensions and the units used. From the previous description it is possible to outline three different fragments of this type of validation:

- Assumptions validation;
- Consistencies validation;
- Relations range validation.

Assumptions – this type of validation has the goal to check and analyze all the assumptions made from the modeler in the construction of the relations between variables.

Consistencies – consistencies validation has the purpose to verify all the dimensions and unit consistencies inside the model.

The dimensions used are consistent when the dimensions on both side of the relation are the same (e.g. → $Time^2 = Time * Time$). The unit used are consistent when only one type of metric is used to measure a specific dimension among the relations.

Relations range – After the evaluation of the consistencies inside a relation it is necessary to evaluate the range on which a relation remain appropriate, in other words it is necessary to evaluate and validate the previously defined range of applicability of the relation. A valid example of this can be the fixed cost definition (that will be discussed in chapter four) where a cost can be considered fixed only inside a certain range of time.

Synoptic validation

The synoptic validation is concerned with the control of the output of the model when it is applied a certain set of input.

As regard the validation of the data model "[…] is concerned with the precision and accuracy of measurement and with whether there has been any bias in the data. One area where bias could arise is from a (deliberate) lack of consistency. […] Another area of bias can arise because the sample of data collected is not representative of all the data"[25]

In conclusion, in the modest opinion of the writer of this thesis, a good decision-maker must know how the output of a mathematical model is generated and also understand the logical path used by the modeler in its model. Using the Information Set given by the model blindly can only leads to a suboptimal, and possibly wrong, decision.

2.2. Deterministic Decision Making

After the description of the managerial context of applicability for a mathematical model it is now possible to discuss and analyze the most common mathematical models and procedures starting from the simplest of them, Linear Programming (LP) models.

Before start with the discussion about Linear Programming models it is useful to give a brief definition about the major topic of this paragraph. Deterministic decision making "concerns managerial decision making in absence of uncertainty. We will assume that we know all there is to know about a particular problem."[26] As it is possible to see form this quote all the next models that will be discussed live and work only under a very strong, and in some scenarios unrealistic, assumption.

2.2.1. Linear programming model

The predominant instruments of deterministic decision making are the Linear Programming models. In these types of models, the goal is to optimize the decision, minimizing or maximizing a specified variable or group of variables, satisfying also certain particular limit conditions.

[25] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 103.
[26] Monahan George E., Management Decision Making, Cambridge University Press, 2000, pg. 2.

The linear programming instrument is useful to solve a vast portion of problem, such as: Product mix problems, blending problems, cutting stock problems, capital budgeting problems, staff scheduling problems, network flow problems, queuing problems and many others. Obviously, as said before, all of these previous problems can be solved with this instrument under the strong assumption of no uncertainty in the problem environment.

The next figure is a representation of an influence diagram for a generic optimization problem.

Note that there are two flow charts as the bottom one is a more general in the terms, but specific in the elements, representation of the first one. Note also that every shades of gray represent the same logical phase for each flow chart.

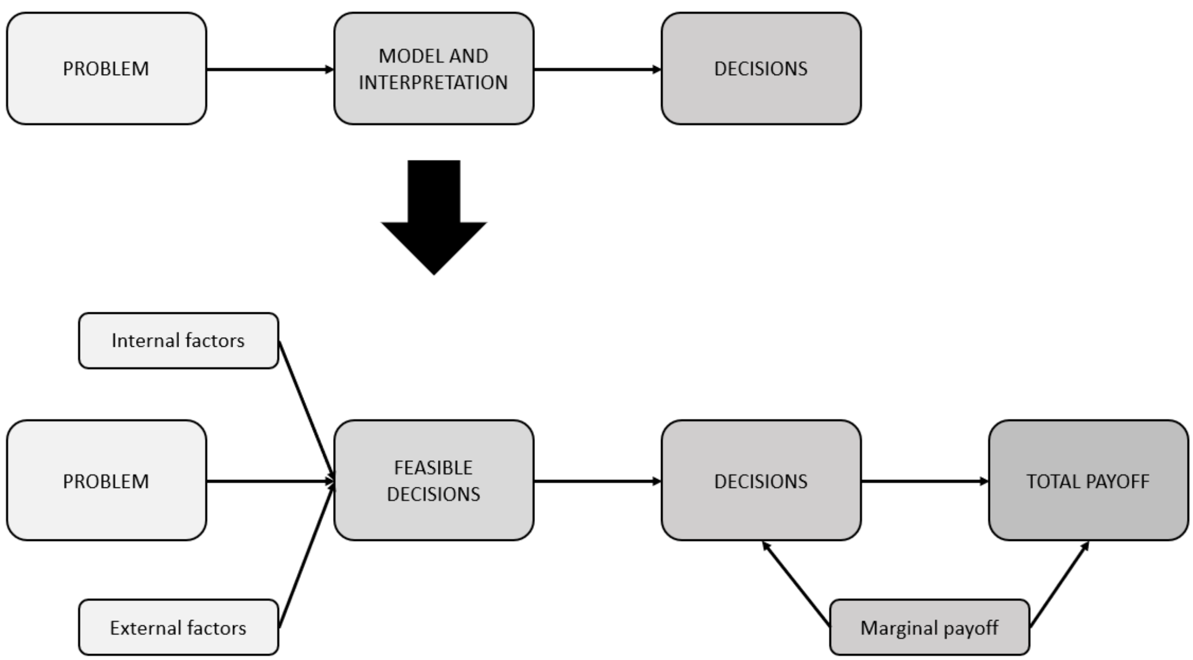


Figure 5 Influence diagram for a generic optimization problem [27]

[27] Partially adapted from: Monahan George E., Management Decision Making, Cambridge University Press, 2000, pg. 30.

As it is possible to see from the second chart, the feasible decisions are determined by the nature of the problem itself plus the influence of internal factors and the external ones, such as resources or technology available, that select from the group of the all possible solutions for the problem, the feasible one. Then, after a measure of the profitability (such as marginal payoff) of all the feasible decisions, the effective set of decisions are taken and the real payoff are visible.

Generally, a decision model can be defined as "[…] the process of translating a written description of a managerial decision problem into terms that make it amenable for analysis on a computer. These terms consist, for the most part, of mathematical relationship. Like all models, our decision model is an abstraction of the reality."[28]

Note the use of the word computer in this quote, nowadays almost every mathematical model (same as for almost every mathematical calculus) works in complement with a pc platform, as the likelihood of a calculus error and the total elaboration time goes above the human ability.

The structure of a general LP decision model is composed by four elements:

- A set of decision variables;
- An objective function;
- Optimization;
- Constraints for the decision variables.

A set of decision variables – the union of all the variables that shapes the problem.

An objective function – the element that determines when a decision is better than another, in correlation with the decision variables;

Optimization – element that describe the optimal value for the decision variables that maximize or minimize the objective function;

[28] Partially adapted from: Monahan George E., Management Decision Making, Cambridge University Press, 2000, pg. 30.

Constraints for the decision variables – Internal or external factors that determine the feasible decisions for the set of decision variables given.

Mathematically speaking, a general LP model can be defined as:

$$Max(Min)\ X_0 = \sum_{j=1}^{r} C_j X_j$$

Formula subject to restrictions:

$$\sum_{j=1}^{r} A_{ij} X_j (\leq, = or \geq) B_i$$

$i = 1, 2, \ldots, m$ $\quad\quad$ $X_j \geq 0$ $\quad\quad$ $j = 1, 2, \ldots, r$

"The modeled system includes several activities j ($j = 1, 2, \ldots, r$) sharing limited resources B_i ($i = 1, 2, \ldots, m$). The usage per unit of the jth activity from the ith resource is A_{ij}. In return for this input, the output (cost or profit) per unit of the jth activity is represented by C_j.

The objective of the model is to determine the level of each activity, X_j, that optimizes (maximizes or minimizes) the output of all activities without violating the limits stipulated on the resources."[29]

After a mathematical definition of a LP model it is useful to define the three basic assumptions under which a Linear model can work:

[29] Moder Joseph J., Elmaghraby Salah E., Handbook of Operations Research: foundations and fundamentals, Litton Educational Publishing, Inc., 1978, pg. 86.

- Proportionality;
- Additivity;
- Non-negativity.

Proportionality – “The usage of the resource for an activity as well as its contribution to the objective function are directly proportional to the level of the activity.”[30]

Additivity – The total usage of resources is equal to the sum of every single resource used by each activity.

Non-negativity – For each activity is not possible to generate, as a result of the linear function, a negative value.

Note that the Proportionality and Additivity properties are these particular elements that produce a linear function.

Linearity is rarely satisfied in real life, in these situations, where the system is non-linear, an LP model can be applied usually by approximating the system with the use of proper assumptions, in this manner, in that particular system, is feasible the use of LP formulations.

There are a lot of instruments that are able to transform a nonlinear system to a linear one, some of these are: hyperbolic or fractional programming, quadratic programming (QP), integer LP and min max criteria. The previous list of transformations will not be discussed in this thesis as not fundamental to the main goal.

Before the definition of the two basic theorems that define the pull of optimal solutions, it is necessary to outline some preliminary steps. First of all, it is necessary to convert all the inequalities in form of equations, this can be done by adding a non-negative slack variable in the left-hand side of every (≤) inequality and subtracting a non-negative surplus variable in the left-hand side of every (≥) inequality.

After this step is useful to express the LPs in matrix notation or vector notation

[30] Moder Joseph J., Elmaghraby Salah E., Handbook of Operations Research: foundations and fundamentals, Litton Educational Publishing, Inc., 1978, pg. 86.

Matrix notation

$$Max(Min)\, X_0 = CX$$

Formula subject to restrictions:

$$AX = B$$

$$X > 0$$

$X = (X_1, \ldots, X_n)$ all the activities vectors that now may include a slack or surplus variable, in addition to the R previously defined decision variables.

Vector notation

$$Max(Min)\, X_0 = \sum_{j=1}^{n} C_j X_j$$

Formula subject to restrictions:

$$\sum_{j=1}^{n} P_j X_j = B$$

$$X_j \geq 0 \qquad\qquad j = 1, 2, \ldots, n$$

Where, usually $m < n,$ this means that the system has an infinite number of possible solutions. There is also another particular situation $m = n$ where the system has only one possible solution. Note that if $AX = B$ is inconsistent, the system has no feasible solution.

"The fundamental property governing the development of the solution method for LP is that its entire (bounded) feasible space (usually consisting of an infinite number of points) can be defined in terms of a finite number of special feasible points."[31]

There are two theorems that demonstrate how these special feasible points can be identified.

First theorem

The optimum solution to a LP, when finite, must be associated with a feasible extreme point of the solution space.

Second theorem

The basic solution of the system $AX = B$ completely define all its extreme points.

The first theorem says that a feasible extreme point is sufficient to identify the solutions of an LP problem. The second theorem instead define how an extreme point can be defined algebraically. In the next sub-paragraph will be discussed the simplex method, useful to define these extreme points with help of what calls, in the jargon, basic solutions.

2.2.2. Simplex method

Before start with the definition of the simplex method it is necessary to define what are the basic solutions.

[31] Moder Joseph J., Elmaghraby Salah E., Handbook of Operations Research: foundations and fundamentals, Litton Educational Publishing, Inc., 1978, pg. 92.

“[…] a basic solution is identified by a basis, that is, by m independent vectors P_j (out of a total of n), all the extreme points of $AX = \sum_{j=1}^{n} P_j X_j = B$ are determined by computing $\frac{n!}{m!(n-m)!}$ possible basic solutions of the system.”[32]

Note that a basic solution can be:

- Nondegenerate;
- Degenerate.

Nondegenerate – when all the basic variables that define that specific extreme point are positive.

Degenerate – when at least one basic variable that define a specific extreme point is equal to zero.

Once defined a basic solution it is possible to continue with the definition of a Simplex method. “Simplex method is a systematic algorithm moving from one basic feasible solution to another so that the objective function value is improved. This procedure of jumping from vertex to vertex is repeated. If the objective function improves at each jump, there is no need to go back to the vertex already covered. As the numbers of vertices is finite, the process leads to the optimal vertex in a finite number of steps”[33]

The simplex method can be considered as an algebraic method (as it is possible to note from the previous definition), although his underlying concepts are geometric one, consequently it is possible to use this method in both variants.

Before explaining the Simplex method procedure, it is necessary to give seven more definitions, in which the first two of them are related with the graphical domain:

[32] Moder Joseph J., Elmaghraby Salah E., Handbook of Operations Research: foundations and fundamentals, Litton Educational Publishing, Inc., 1978, pg. 93.
[33] Srinivasan R., Strategic Business Decisions: a quantitative approach, Springer, 2014, pg. 23.

Constraint boundary – A line that divides the area of permitted solutions, defined by the restrictions, from the area of non-permitted solutions. The union of all constraint boundaries outline the feasible region.

CPF solutions – (Corner-Point Feasible solutions) represent the group of points generated by the intersection between two or more constraint boundaries that lies on the corner of the feasible region.

Slack variable – A slack variable is a particular type of variable added to an inequality with the purpose to obtain an equation.

Augmented solution – An augmented solution is the "new" solution for the original variables obtained after the addition of the slack variables.

Artificial variable – An artificial variable is a particular type of variable whose aim is to reach the identity for the matrix in the tabular representation of the simplex method.

Basic variable – A basic variable is a particular type of variable that in the simplex system have a value greater than zero. This value is obtained through the simultaneous solution of the augmented system of equations.

Non-basic variable – A non-basic variable is a variable that is set, from the problem solver, to zero.

BF solution – (Basic Feasible Solution) is an augmented CPF solution.

The simplex method is based on a simple, but efficient, iterative algorithm. This particular process can be represented, as follow, through the use of a flow chart:

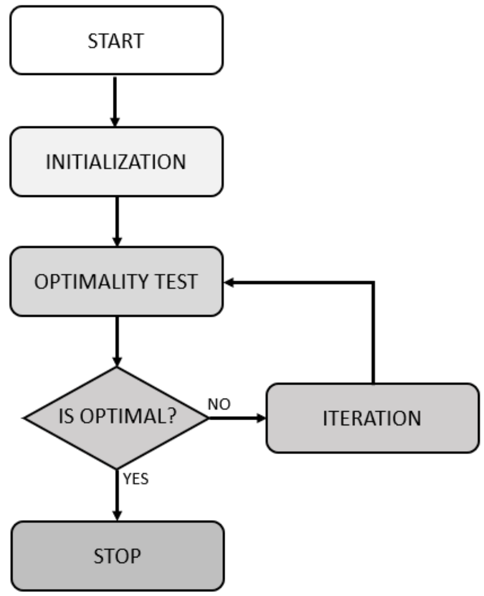


Figure 6 Simplex method flow chart

Graphically speaking the three main steps can be defined as follow:

Initialization

The first step consists in choosing one arbitrary CFP. Usually the first CFP is the origin (0 ; 0) as there are no calculations needed to find this point.

Optimality test

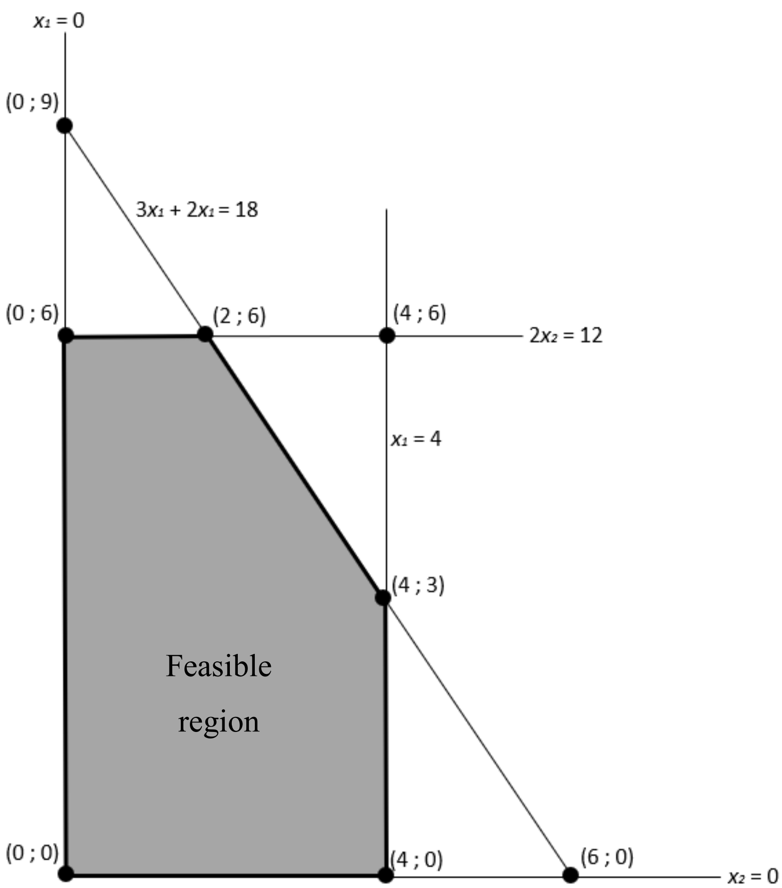
In the second step a verification for the optimality of the solution found is necessary. This operation consists in the calculation of the solution (Z) for the chosen CFP, and consequently the verification that no adjacent CFP have a better solution.

Iteration

The third step is activated only if, from the previous step, a CFP with a better solution is found. In this particular scenario it is necessary to "move" to the better solution through calculating that related adjacent CFP. Once done, it is necessary to go back to the second step.

The previous three steps have to be reiterated until the result of the optimality test show that the optimal CFP is found.

After the needed definitions, it is now possible to bring an example of graphical solution for a given LP problem:



$Maximize \rightarrow\ Z = 3x_1 + 5x_2$

Formula subject to restrictions:

$x_1 \leq 4$

$2x_2 \leq 12$

$2x_1 + 3x_2 \leq 18$

And:

$x_1 \geq 0, \quad x_2 \geq 0$

Figure 7 Example of a graphical solutions to an LP problem [34]

[34] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 82.

Each dot in the figure represents a possible, but not consequently feasible nor optimal, corner point solution for the system of equations generated by the hypothesis inside the black square.

As regards the optimal solution it can be found with the next series of steps:

1. **Initialization** → Chose (0 ; 0);

2. **Optimality test** → (0 ; 0) is not an optimal solution. Adjacent solutions of CFP (0 ; 6), (4 ; 0) are better;

3. **Iteration 1** → Move to adjacent better CFP (0 ; 6);

4. **Optimality test** → (0 ; 6) is not an optimal solution. Adjacent solution of CFP (2 ; 6) is better;

5. **Iteration 2** → Move to adjacent better CFP (2 ; 6);

6. **Optimality test** → (2 ; 6) is an optimal solution. No better adjacent CFP solutions;

As it is intuitable from the previous flow chart, bearing in mind the previous example (figure 6), through this algorithm it is possible to find the optimum point with a limited number of calculations, reducing the total payload for the calculator and also reducing the total computing time necessary to get the optimal solution.

Nowadays almost all the mathematical computations are done by a computer, consequently, to continue with the discussion about the simplex method, it is necessary to make a transition from the graphical domain to the algebraic one.

The next figure clarifies the connection between the two domains, from a logical and terms side.

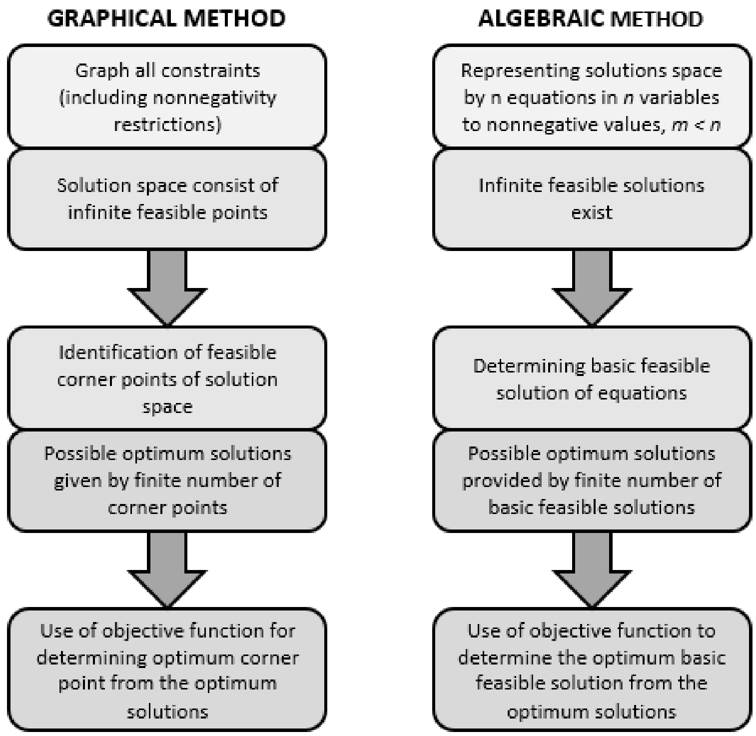


Figure 8 Transition from graphical to algebraic domain [35]

Note that the previous figure represents the common procedure to solve an LP problem from a graphical and algebraic point of view and not the conceptual procedure of the simplex method.

After the needed definitions and clarifications, it is now possible to continue with the discussion about the computational procedure of the simplex method. This particular algebraic procedure is composed by nine different steps defined as follow:

1) Problem conversion;
2) Constraint conversion;

[35] Srinivasan R., Strategic Business Decisions: a quantitative approach, Springer, 2014, pg. 24.

3) Inequality conversion;
4) Define basic matrix identity;
5) Construct starting simplex table;
6) Optimality test;
7) Improvement of variables;
8) Construct improved simplex table;
9) Iteration process.

Note that from step one to four, the related process represents the classical procedure to solve an LP problem. Taking in further consideration the fact that this particular representation is a tabular variant of the pure algebraic procedure, handy to do calculations by hand but also usable by a computer as formed by a matrix composed by a system of equations.

Step 1 - Problem conversion

The first step in the simplex procedure consists in the conversion of the given problem in a maximization type if it is represented as a minimization type (this can be done by multiplying both sides of the function by -1)

.

Step 2 - Constraint conversion

The second step consists in the conversion of all the negative constraints in non-negative one (by multiply both sides of the constraint by -1).

Step 3 - Inequality conversion

The third step consists in the conversion of all the inequalities into equations through the use of slack or surplus variables.

Step 4 - Define basic matrix identity

In the fourth step, artificial variables are added to the ≥ and = constraints to obtain the basis identity of the matrix.

Step 5 - Construct starting simplex table

In the fifth step, the available data are used to generate the starting simplex table. To better understand this step the next table represents the exoskeleton of a simplex table.

Basic Variable	Eq.	Coefficient of:							Right side	Minimum Ratio
		Z	X_1	X_n	S_1	S_n	A_1	A_n		
Z	(0)									
S_1	(1)									
S_2	(2)									
S_3	(3)									
S_n	(n)									
Note: S_1 … S_n → Slack variables; A_1 … A_n → Artificial variables Right side represents the other side of the equation Minimum ratio is needed to determine the first leaving basic variable										

Table 2 Representation of an empty simplex table

Step 6 - Optimality test

The sixth step consists in the verification of the optimality of the current solution. If every coefficient in row (0) is non-negative an optimal solution is reached, if not, an improvement of the simplex table is needed.

Step 7 - Improvement of variables

The seventh step consists in the substitution of a basic variable with a non-basic one. The exiting variable should be that specific variable in which the value of the minimum ratio is lower. The entering variable should be the one that, if increased, gives the greater improvement of Z in comparison with the others non-basic variables.

Step 8 - Construct improved simplex table

The eighth step, as intuitable from the definition, consists in the generation of a new simplex table with the previously improved data.

Step 9 - Iteration process

The ninth and last step consists in the iteration of step 6, 7, 8, 9. As said before, the simplex method is an iterative algorithm, consequently, the last four steps should be repeated until the optimal solution is obtained.

To conclude the discussion about the simplex method it is useful to give the algebraic interpretation of the geometric procedure for the example of figure 6. The next table is adapted from the book: Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research.

Method sequence	Geometric Interpretation	Algebraic interpretation
Initialization	Choose (0 ; 0) to be initial CPF.	Choose x_1 and x_2 to be the non-basic variables (=0) for the initial BF (Basic Feasible) solution: (0, 0, 4, 12, 18).
Optimality test	Not optimal, because moving along either edge from (0 ; 0) increase Z.	Not optimal, because increasing either non-basic variable (x_1 or x_2) increase Z.
Iteration 1		
Step 1	Move up the edge lying on the x_1 axis.	Increase x_2 while adjusting other variable values to satisfy the system of equations.
Step 2	Stop at the first new constraint boundary ($2x_2 = 12$) is reached.	Stop when the first basic variable (s_1, s_2 or s_3) drop to zero (s_2).
Step 3	Find the intersection of the new pair of constraint boundaries: (0 ; 6) is the new CFP solution.	With x_2 now a basic variable and s_2 now a non-basic variable, solve the system of equations: (0, 6, 4, 0, 6) is the new BF solution.

Optimality test	Not optimal, because moving along the edge from (0 ; 6) to the right increase Z.	Not optimal, because increasing one variable (x_1) increase Z.
Iteration 2		
Step 1	Move along the edge to the right.	Increase x_1 while adjusting other variable value to satisfy the system of equations.
Step 2	Stop when the first constraint boundary ($3x_1 + 2x_2 = 18$).	Stop when the first basic variable (s_1, x_2 or s_3) drop to zero (s_3).
Step 3	Find the intersection of the new pair of constraint boundaries: (2 ; 6) is the new CFP solution.	With x_1 now a basic variable and s_3 a non-basic variable, solve the system of equations: (2, 6, 2, 0, 0) is the new BF solution.
Optimality test	(2 ; 6) is optimal, because moving along either edge from (2 ; 6) decreases Z.	(2, 6, 2, 0, 0) is optimal, because increasing either non-basic variable (s_2 or s_3) decreases Z.

Table 3 comparison between algebraic and geometric interpretations of the figure 6 example [36]

2.3. Mathematical models for specific scenarios

"The first step in learning the art of modeling is to get acquainted with a few standard problems, which can be regarded as paradigm, as well as building blocks for more realistic and interesting problems. […] most real-life problems contain part or variations of these prototypes as a submodels." [37] As is intuitable form the previous quote, the aim of this paragraph is to provide a

[36] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 91.
[37] Brandimarte Paolo, Quantitative Methods: an introduction for business management, John Wiley and Sons, Inc., 2011, pg. 608.

series of common basic problems and its most efficient solutions, as almost every large scale problems can be divided in sub-problems, some of which are likely to be similar to these ones.

2.3.1. Transportation Problem

The first type of problem taken into consideration is the transportation problem. In this particular type of problem, the purpose is to transport various amount of homogeneous goods, stored in various locations, to a series of different destinations in such a way that the total shipping cost is minimized.

This problem can be expressed mathematically as follow:

$$Min\ Z = \sum_{j=1}^{n}\sum_{i=1}^{m} C_{ij}X_{ij}$$

Formula subject to restrictions:

$$\sum_{j=1}^{n} X_{ij} = A_i \ ; \ X_{ij} \geq 0 \ ; \ \forall\, i \ = \ 1, 2, \dots, m$$

$$\sum_{i=1}^{m} X_{ij} = B_j \ ; \ X_{ij} \geq 0 \ ; \ \forall\, j \ = \ 1, 2, \dots, n$$

$$(\textstyle\sum A_i) = \left(\textstyle\sum B_j\right) \ \forall\, i \ = \ 1, 2, \dots, m \ ; \ \forall\, j \ = \ 1, 2, \dots, n$$

As it is possible to notice, the formulation of the problem is pretty similar to a Linear Programming Problem (LPP).

Suppose that m are the sources and A_i the number of units in that source, n are the destinations and B_j the number of pieces needed in that specific destination. Lastly, suppose that C_{ij} is the cost to ship one unit from the ith sources location to the jth destination and X_{ij} the number of units required from the ith source location to the jth destination.

The last line in the formula table is dedicated to the assumption that the total unit needed at destination is equal to the total unit in disposition in the sources. Note that this leads to a balanced transportation problem. It is also possible to solve an unbalanced transportation problem $\{(\sum A_i) \neq (\sum B_j) \ \forall\, i = 1, 2, \ldots, m \ ; \ \forall\, j = 1, 2, \ldots, n\}$ by adding some dummy sources or destinations to rebalance the formula.

Once mathematically defined the problem it is now possible to move toward the solution procedure, in this scenario the algorithm used to reach the solution is the simplex one.

As defined in sub-paragraph 2.2.2. the simplex method is composed by 3 steps:

- Initialization;
- Optimality test;
- Iteration.

These three steps can be tackled for this problem as follow.

Initialization

As regard this first step, after a rigorous verification of the balance between sources and destinations, there are five common methods for the initialization of a transportation problem at the purpose of obtaining the IBFS (Initial Basic Feasible Solution):

- North-West Corner rule;
- Row Minima method;
- Column Minima method;

- Lowest Cost Entry method;
- Vogel's approximation method.

North-West Corner rule – In the North-West corner allocation method the starting point, as it is intuitable from the name, is the top left cell. The allocation logic is the following: take into consideration the total supply units for the first source, and with that value try to fulfill the demand of the first destination. Then, if the demand of the first destination is satisfied, keep the same row but move to the next column (go to the left cell) and subtract to the current supply value the previous demand value. If not, keep the same column but move to the next row (go to the lower cell) and subtract to the current demand value the previous supply value. Repeat the process until all the resources will be allocated.

The next table represents a numerical example of the North-West Corner rule.

Source	**Destination**							**Supply**
	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	
S1	30 →	40 →	20 ↓					**90**
S2			30 →	60 →	10 ↓			**100**
S3					60 →	50 ↓		**110**
S4						30 →	90	**120**
Demand	**30**	**40**	**50**	**60**	**70**	**80**	**90**	

Table 4 example of the North-West Corner rule

Row Minima method – In the Row Minima method the logic behind the allocation of resources follows the principle of the minimum cost, consequently, as the name suggests, all the possible resources of the first row will be allocated to the destination with the lowest cost in that row. Then, if the demand of the first destination is satisfied, keep the same column, subtract to the current supply value the current demand value and move to the next cell with the lowest transportation cost in the row. If not, move to the next row and subtract to the current demand value the previous supply value. Repeat the process until all the resources will be allocated. Note that the starting row in this method is the upper row.

The next table represents a numerical example of the Row Minima method.

Source	Destination							Supply
	D1	D2	D3	D4	D5	D6	D7	
S1	(5)	(7)	(10)	(11)	(6)	(4)	90(2)	**90**
S2	30(2)	(5)	(10)	(8)	70(4)	(13)	(3)	**100**
S3	(3)	30(8)	(9)	(14)	(6)	80(1)	(16)	**110**
S4	(5)	10(7)	50(10)	60(11)	(4)	(4)	(9)	**120**
Demand	**30**	**40**	**50**	**60**	**70**	**80**	**90**	
Note: the value between the two parentheses ( ) represents the transportation cost related to that specific combination Source-Destination								

Table 5 example of Row Minima method

Column Minima method – In this particular method the logic is similar to the previous method but, in this case, it is necessary to choose the cell with the lower transportation cost in the column and allocate to it the total possible resources of that row. Consequently, if the demand of the first destination is satisfied, move to the next column and subtract to the current supply value the previous demand value. If not, keep the same column, subtract to the current demand value the current supply value and move to the next cell with the lowest transportation cost in the column. Repeat the process until all the resources will be allocated. Note that the starting column in this method is the left column.

The next table represents a numerical example of the Column Minima method.

Source	Destination							Supply
	D1	D2	D3	D4	D5	D6	D7	
S1	(5)	(7)	(10)	30(11)	(6)	20(4)	40 (2)	**90**
S2	30 (2)	40 (5)	(10)	30(8)	(4)	(13)	(3)	**100**
S3	(3)	(8)	50(9)	(14)	(6)	60 (1)	(16)	**110**
S4	(5)	(7)	(10)	(11)	70(4)	(4)	50(9)	**120**
Demand	**30**	**40**	**50**	**60**	**70**	**80**	**90**	
Note: the value between the two parentheses ( ) represents the transportation cost related to that specific combination Source-Destination								

Table 6 example of the Column Minima method

Lowest Cost Entry method – The lowest cost entry method is also known as the Matrix Minima method. In this particular method the starting cell is the one with the least transportation cost. Once the cell is optimized, and the related adjustments are made to their demand and supply, it is necessary to move to the next cell with the lowest transportation cost in the matrix and repeat the process.

The next table represents a numerical example of the Lowest Cost Entry method.

Source	Destination							Supply
	D1	D2	D3	D4	D5	D6	D7	
S1	(5)	(7)	(10)	(11)	(6)	(4)	90 (2)	**90**
S2	30 (2)	40 (5)	(10)	30(8)	(4)	(13)	(3)	**100**
S3	(3)	(8)	30(9)	(14)	(6)	80 (1)	(16)	**110**
S4	(5)	(7)	20 (10)	30(11)	70(4)	(4)	(9)	**120**
Demand	**30**	**40**	**50**	**60**	**70**	**80**	**90**	
Note: the value between the two parentheses ( ) represents the transportation cost related to that specific combination Source-Destination								

Table 7 example of the Lowest Cost Entry method

Vogel's approximation method – "For each row and column remaining under consideration, calculate its difference, which is defined as the arithmetic difference between the smallest and next-to-the-smallest unit cost still remaining in that row or column. (if two unit costs tie for being the smallest remaining in a row or column, then the difference is 0) In that row or column having the largest difference, select the variable having the smallest remaining unit costs. (Ties for the largest difference, or for the smallest remaining unit cost, may be broken arbitrarily.)"[38]

To better understand the procedure, the next table represents a numerical example of the Vogel's approximation method.

Source	Destination							Supply	Row Difference
	D1	D2	D3	D4	D5	D6	D7		
S1	(5)	(7)	(10)	10(11)	(6)	80(4)	(2)	**90**	**2**
S2	10(2)	40(5)	(10)	50(8)	(4)	(13)	(3)	**100**	**1**
S3	20(3)	(8)	50(9)	(14)	(6)	(1)	40(16)	**110**	**1**
S4	(5)	(7)	(10)	(11)	70(4)	(4)	50(9)	**120**	**0**
Demand	**30**	**40**	**50**	**60**	**70**	**80**	**90**		
Column Difference	**1**	**2**	**1**	**3**	**0**	**3**	**1**		
Note: the value between the two parentheses ( ) represents the transportation cost related to that specific combination Source-Destination									

Table 8 example of the Vogel's approximation method

Note that each one of these allocation methods have their particular advantages or disadvantages as IBFS, depending on the given situation.

[38]Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 320.

Optimality test

As usual, in the simplex method process seen in the previous paragraph, after the initialization process, a verification of degeneracy and an optimality test is required.

The most common procedure towards the optimality test in this given situation is the U-V method where, algebraically, a given solution can be considered optimal if and only if for every $C_{ij} - U_i - V_j \geq 0$ (i, j) such that X_{ij} is non-basic, where U is the multiplier associated with each row and V is the multiplier associated with each column. The formula under which is possible to calculate these multipliers is the following: $C_{ij} = U_i + V_j$ for every (i, j) such that X_{ij} is basic, note that a cell is basic if contains a value.

In this particular method a first initial multiplier value is set to zero, and consequently, the other multipliers are calculated trough the previously given formula. A convenient choice for the initial multiplier is the row with the highest number of allocations with the only purpose to simplify the calculus related with the other multipliers.

Iteration

The iteration process is activated if and only if $C_{ij} - U_i - V_j \geq 0$ (i, j) such that X_{ij} is non-basic "rule" is not respected. This particular step is composed by 2 sub-steps that can be explained as follow

Sub-step 1 – As usual the first iteration step is to select the non-basic variable to be changed in basic variable, in this scenario the rule is to choose the cell with the most negative value (in absolute terms) resulting from the previous formula.

Sub-step 2 – The consequence of the first sub-step is a chain reaction in which the new entry basic variable is increased and all the other correlated cells to that row and column are adjusted to restore the supply and demand related to that particular row and column, this process continue until one of the adjusted basic variables become zero. Obviously, if a non-basic variable become a basic variable, a leaving basic variable is needed, in this scenario, the leaving variable is the one with the smallest allocation.

As usual form the simplex method, this process will continue until the new BF solution respect the optimality test rule.

2.3.2. Networks problem

Before starting this argument, it is necessary to understand the concept of network and its main elements.

The following quote contains a definition of network insert in the production context. “A network is a collection of nodes and arcs. Let *N* be the set of nodes, which are typically physical locations. Arcs represents links between pairs of locations and are actually pairs (*i, j*) of nodes. If the pair is oriented, we have a directed network; otherwise we have an undirected network. In a directed network, arcs have a specific direction along which items flow. Let us denote this set of arcs by *A* which is a subset of the Cartesian product of nodes, $A \subseteq N \times N$. Numerical information may be attached to arcs, such as transportation capacity, and nodes, such as the minimum throughput of a logistic facility.” [39]

The following example consist in a graphical and tabular representation of a network.

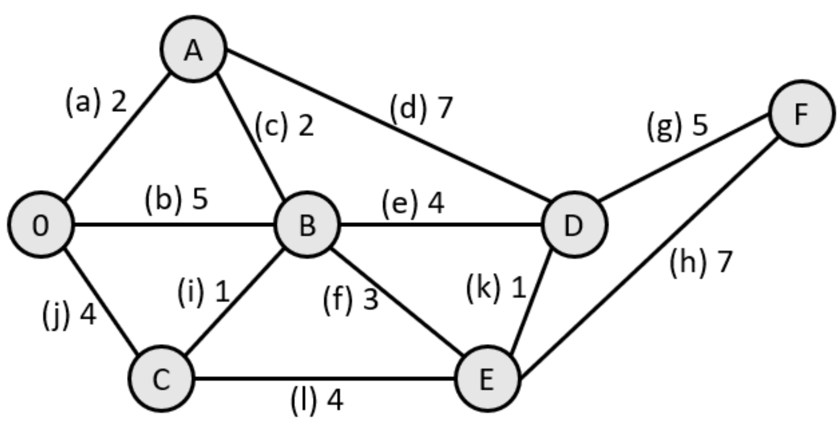


Figure 9 representation of an undirected network in a graphical form [40]

[39] Brandimarte Paolo, Quantitative Methods: an introduction for business management, John Wiley and Sons, Inc., 2011, pg. 624.
[40] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 355.

$$
\begin{array}{cc}
 & \begin{matrix} a & b & c & d & e & f & g & h & i & j & k & l \end{matrix} \\
\begin{matrix} 0 \\ A \\ B \\ C \\ D \\ E \\ F \end{matrix} &
\begin{bmatrix}
1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\
0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0
\end{bmatrix}
\end{array}
$$

Table 9 Tabular representation of the network on figure 9

Note that, theoretically, in the example scenario it is more correct to define the nodes as vertices and the arcs as edges, since the network is undirected. Additionally, if the network is directed, the values changes a little bit in the matrix representation as, in this particular case, it is necessary to put 1 for an input arch and -1 for an output arch. Another thing that changes in this scenario is that in the graphical representation the arches are represented by arrows that points towards the direction of the flow.

To thoroughly understand the concept of network some more definitions are needed:

Arch capacity – The maximum permitted flow of units for each arch.

Sink node – A sink node is a particular type of node where the inflow of units is greater than the outflow.

Source node – Differently from the previous definition, a source node is a particular type of nodes where the inflow of units is lower than the outflow.

Transshipment node – A transshipment node satisfies the conservation of flow or the total inflow is equal to the total outflow.

It is useful to remember that a network can represents almost everything, from a group of firms that share information/products to a production process or a group of people or knowledge.

After these clarifications, it is now possible to move towards the definition of the typical problems related to a network, under a managerial point of view.

In the network field it is possible to find three main problem categories:

- The shortest-path problem;
- The minimum spanning tree problem;
- The maximum flow problem;

Shortest-path

The shortest directed path problem, or shortest-path problem, consists in finding the shortest path (minimum distance) between two specific nodes, called origin and destination, in an undirected and connected network. There are several algorithms able to solve this problem, one of the most efficient of them is the Dijkstra algorithm.

"Given a net $G(V, E)$ with node set V and arc set E, suppose that each arch $(i, j) \in E$ is associated with a real number $l(i, j)$ called the length of the arc (i, j). The function l from the arc set E to the reals is the length function."[41]

Given a net $G(V, E, l)$ with non-negative arch lengths [$l(i, j) \geq 0$ for all $(i, j) \in E$] the algorithm able to find the shortest path from a given node s is composed by the three following steps.

Step 1 – Set $l^*(s) = 0$ and $l(i) = l(s, i)$ for $i \neq s$ and $i \in V$, where $l(s, i) = \infty$ for $i \neq s$ and $(s, i) \notin E$.

[41] Chen Wai-Kai, Theory of Nets: flows in networks, John Wiley & Sons, Inc., 1990, pg. 100.

Step 2 – Among all temporary labels *l(i),* pick $l(k) = \min_i l(i)$, change *l(k) to l*(k).* Stop if there is no temporary label left.

Step 3 – Update all temporary labels of the nodes *i* with *(k, i) ∈E* for all *i* by *l(i) = min[l(i), l*(k) + l(k, i)]*. Return to step 2.

---

[42]

After defining the algorithm and its compositions, it is now possible to apply this algorithm in the net represented in figure 9. In this particular net the starting node *s* is 0 and the ending node is F and the shortest-path is computed exploiting the Dijkstra algorithm, as follows.

Step 1 – The starting node 0 receive the label *l*(s) = 0.*

Node A, B, C receives the labels *l(A) = 2 ; l(B) = 5 ; l(C) = 4.*

The others node receives the labels *l(i) = ∞.*

Step 2 – pick *l(1) = min [l(i)]* → *k = 1.*

This change *l(A)* to *l*(A) = 2* for node A.

Step 3 – *l(D) = min [l(D), l*(A) + l(A, D)] = min [∞, 2 + 7] = 9*

l(B) = min [l(B), l(A) + l (A, B)] = min [5, 2 + 2] = 4*

Go to step 2.

Repeat the iteration until step 2 there are no temporary labels left.

In the next figure it is represented the transformation between the starting network and the resulting one.

[42] Chen Wai-Kai, Theory of Nets: flows in networks, John Wiley & Sons, Inc., 1990, pg. 103.

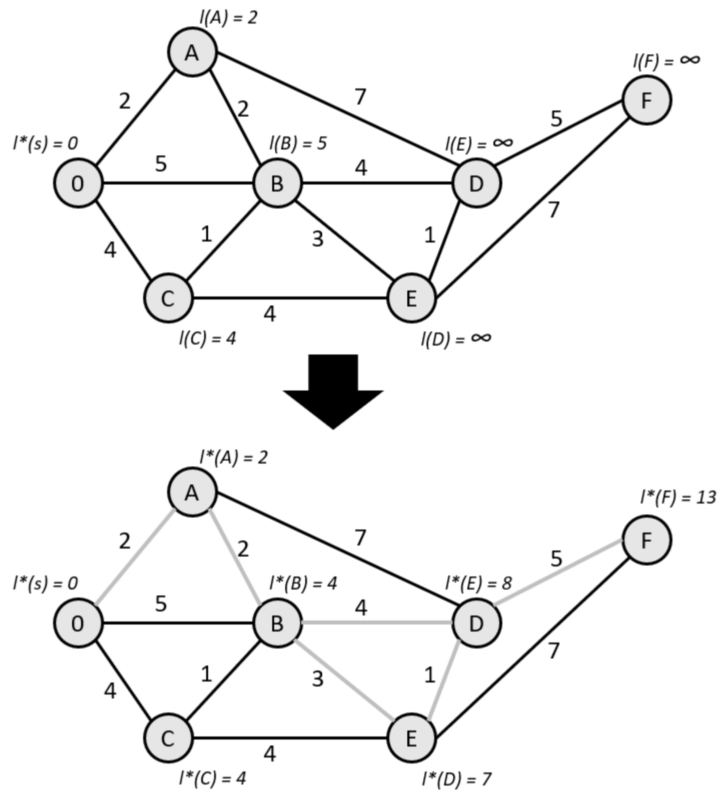


Figure 10 Solution of the shortest-path problem for the figure 9

Note that the shortest path is marked in gray. Particular attention has to be payed in noticing that in this example there are two different shortest-path because B → D and B → E → D have the same length of 4.

Minimum spanning tree

The minimum spanning tree problem is very similar to the shortest-path problem, as a matter of facts, in both scenarios is considered an undirected and connected network complete of relative distance between each node. The great difference between them is that the objective of the minimum spanning tree is to find the shortest total length among all sets of links, where the only restriction is that the links have to provide a path between each pair of nodes.

The algorithm designated for this particular problem is the Kruskal one.

Step 1 – Select the shortest edge of $G(V, E, l)$ and color it in blue. Set $i = 0$.

Step 2 – Among the edges not yet chosen, select the shortest edge (x, y). If nodes x and y belong to the same subtree, color (x, y) in red; otherwise, color it in blue.

Step 3 – Set $i = i + 1$.

Step 4 – If $I = m - 1$, stop, where m is the number of edges of G. Otherwise, return to step 2.

43

Note that the net must be arranged in a non-decreasing order by length. The representation with colors (blue, red) is not mandatory, as its only purpose is to help in the graphical representation.

It is now possible to implement the algorithm in the example of figure 9.

Step 1 – Select edge (B, C) and color it in blue, set $i = 0$.

Step 2 – Select edge (D, E) and color it in blue.

Step 3 – Select $i = 1$.

Step 4 – Return to step 2.

Repeat the iteration until $i = m – 1$.

[43] Chen Wai-Kai, Theory of Nets: flows in networks, John Wiley & Sons, Inc., 1990, pg. 259.

In the next figure is represented the minimum spanning tree of figure 9.

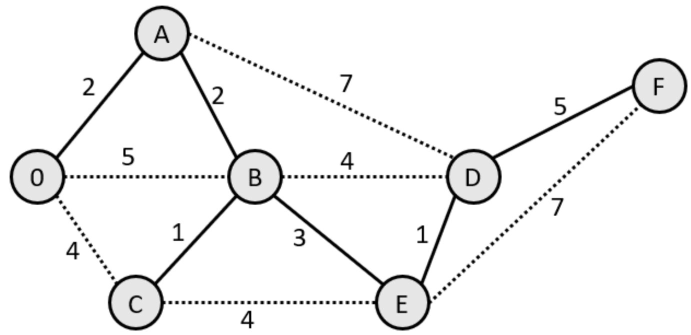


Figure 11 Solution of the spanning tree problem for the figure 9

Note that in this case a dotted line represents the red color, and a solid line represents the blue color.

Maximum flow

As usual, regarding the discussion about problems, it is necessary to start from the definition. The maximum flow problem can be defined as follow "Il problema di flusso massimo richiede di determinare il massimo numero di unità di prodotto che possono essere inviate da *s* a *t* lungo gli archi di *G*, ovvero di determinare il flusso ammissibile che massimizza il valore di *v*."[44]. Note that, in this scenario the network must be directed.

One of the possible designated algorithms for the solution of the maximum flow problem in a network is the Ford-Fulkerson one. This particular algorithm consists in two different routines, the first one is a labeling routine, where the nodes are labelled. The second one is an augmentation routine, where the labels are increased/decreased following certain rules.

The two routines can be defined as follow.

[44] Vercellis Carlo, Modelli e Decisioni: strumenti e metodi per le decisioni aziendali, Società Editrice Esculapio S.r.l., 1997, pg. 257.

Labelling routine

Step 1 – Label s by (s, +, ∞). Now s is labeled and unscanned and all other nodes are unlabeled and unscanned.

Step 2 – Select any labeled and unscanned node x, and perform the following operations:

a) For all nodes y, $(x, y) \in E$, that are unlabeled such that $f(x, y) < c(x, y)$, label y by $(x, +, w(y))$ where $w(y) = min\,[w(x), c(x, y) - f(x, y)]$. Then y is labeled and unscanned.

b) For all nodes y, $(y, x) \in E$, that are unlabeled such that $f(y, x) > 0$, label y by $(x, -, w(y))$ where $w(y) = min[w(x), f(y, x)]$. Now change the label on x by circling the + or – entry. Then x is now labeled and scanned.

Step 3 – Repeat step 2 until either t is labeled or until no more labels can be assigned and t is unlabeled. In the former case, go to the Augmentation routine; in the latter case, terminate.

[45]

Augmentation routine

Step 1 – Let $z = t$ and go to step 2 below.

Step 2 – If the label on z is $(q, +, w(z))$, increase the flow $f(q, z)$ by $w(t)$.

If the label on z is $(q, -, w(z))$, decrease the flow $f(q, z)$ by $w(t)$.

[45] Chen Wai-Kai, Theory of Nets: flows in networks, John Wiley & Sons, Inc., 1990, pg. 185.

Step 3 – If $q = s$, discard all labels and return to step 1 of the Labeling routine. Otherwise let $z = q$ and return to step 2 of the Augmentation routine.

---

[46]

After the needed definitions, about the algorithm and its compositions, it is now possible to apply this particular algorithm in the network represented the directed version of the net in figure 9, represented in the figure below.

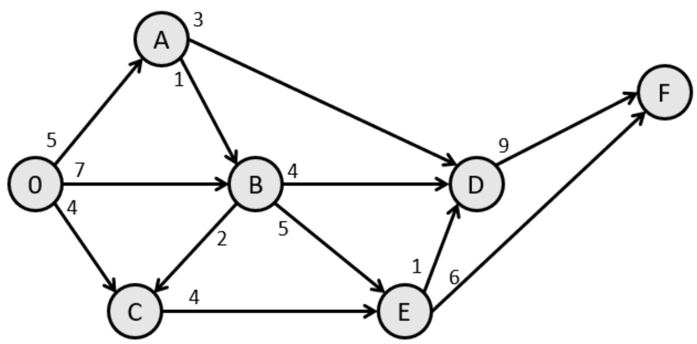


Figure 12 Directed network form the example on figure 9 [47]

Note that the numbers near the starting point of each arch represents the maximum flow of unit admitted, note also that at the end of each arch usually is written the total number of units flowed.

First iteration - Labeling Routine.

Step 1 – Label *0* by ($0, +, \infty$).

[46] Chen Wai-Kai, Theory of Nets: flows in networks, John Wiley & Sons, Inc., 1990, pg. 185.
[47] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 367.

Step 2 – Node A label ($0, +, 5$), node B label ($0, +, 7$) node C label ($0, +, 4$). Circle the + in ($0, +, \infty$) giving ($0, \oplus, \infty$).

Step 3 – Return to step 2.

Step 2 – Node D label ($B, +, 4$), node E label ($B, +, 5$). Circle the + in ($0, +, 4$), ($0, +, 5$) and ($B, +, 7$) giving ($0, \oplus, 4$), ($0, \oplus, 5$) and ($0, \oplus, 7$).

Step 3 – Return to step 2.

Step 2 – Node F label ($E, +, 5$), and change ($B, +, 5$) and ($B, +, 4$) to ($B, \oplus, 5$) and ($B, \oplus, 4$).

Step 3 – Go to Augmentation Routine.

First iteration - Augmentation Routine.

Step 1 – Let $z = F$.

Step 2 – Increase the flow $f(E, F)$ by 5.

Step 3 – Set z = E.

Step 2 – Increase the flow $f(B, E)$ by 5.

Step 3 – Set z = B.

Step 2 – Increase the flow $f(0, B)$ by 5.

Step 3 – Discard all labels, return to step 1 of the Labeling Routine.

Repeat the iteration cycle until no more labels can be assigned and F is unlabeled.

The following figure represents the result for the example of figure 12: after the first iteration and the final result.

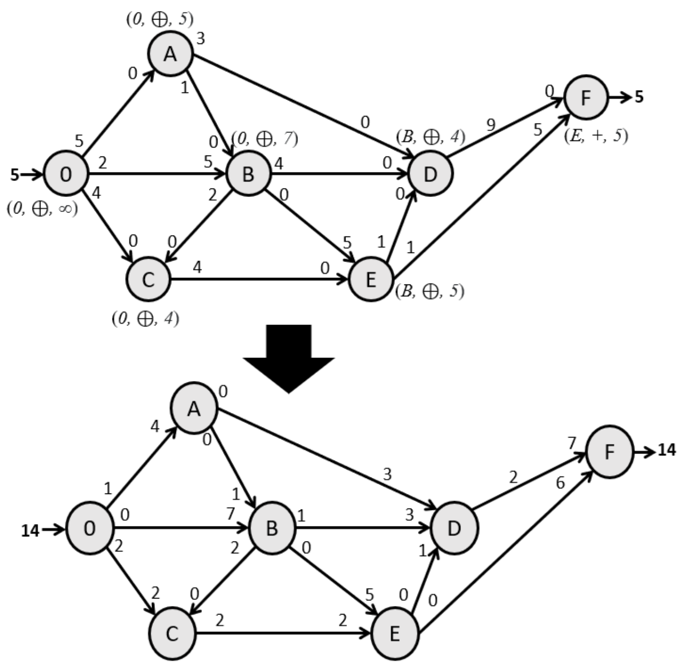


Figure 13 network result: after the first iteration and the final result

As said before, networks can be used to represents almost everything. In the managerial field, networks are also used for the representation of project and process. In this particular scenario a new, fundamental, variable must be considered: Time.

The most commonly used time-control instruments related to the networks are:

- CPM (Critical-Path method)
- PERT (Program Evaluation and Review Technique)

As a matter of fact, they are commonly collapsed in the "PERT-type system" definition, also if there are some important differences between them. The purpose of the use of this analysis system can be greatly described as follow "A PERT-type systems is designed to aid in planning and control, so it may not involve much direct optimization. Sometimes one of the primary objectives is to determine the probability of meeting specific deadlines. It also identifies the activity that are most likely to be bottlenecks, and, therefore the places where the greatest effort should be made to stay on schedule. A third objective is to evaluate the effect of changes in the program. […] another important use is to evaluate the effect of deviations from schedule." [48]

As usual, with the introduction of a new "dimension" it is necessary to give some fundamental definitions.

Project network – As intuitable from the name the project network is the basilar network that represents the project or process.

There are two different way to represent a project network:

- AOA (Activity On Arrows) where for arrow is intended arch.
- AON (Activity On Nodes)

Activity – An activity represents a task required by the project or process.

Event – An event represents the status of the "moving" entity in the network.

Critical-Path Method (CPM)

In the CPM system representation, there are three more fundamental elements:

Earliest start (end) time – The Earliest start (end) time have the purpose to outline the estimated time at which an activity can start (end) if all the previous activities have started as early as possible.

[48] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 389.

Latest start (end) time – The Latest start (end) time have the purpose to outline the estimated time at which an activity can start (end) if all the previous activities have started as late as possible, without delaying the process beyond its earliest end time.

Slack – The slack variable represents, for an activity, the difference between its earliest and latest starting (ending) time.

Consequently, the Critical Path Method, as intuitable from the denomination, have the main purpose of calculating the path that have a total slack equal to zero.

The following figure is an example of project network represented with the AON technique.

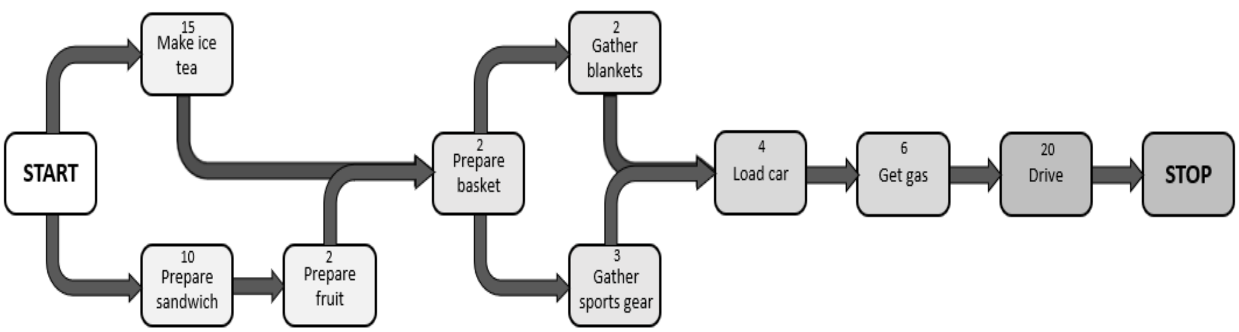


Figure 14 Example of a PERT-type process for preparing a picnic with the AON technique [49]

Note that on top of each activity is represented the expected duration of that particular activity.

Regarding the previous example the results of an CPM analysis can be represented with the following table.

[49] Roman Daniel D., Managing Projects: a systems approach, Elsevier Science Publishing Co., Inc., 1986, pg. 147.

Activity	Earliest start time	Earliest end time	Latest start time	Latest end time	Slack
Make ice tea	0	15	0	15	0
Prepare sandwich	0	10	3	13	3
Prepare fruit	10	12	13	15	3
Prepare basket	15	17	15	17	0
Gather blankets	17	19	18	20	1
Gather sports gear	17	20	17	20	0
Load car	20	24	20	24	0
Get gas	24	30	24	30	0
Drive	30	50	30	50	0

Table 10 Resulting CPM table for the example of figure 14

As it is possible to extrapolate form the table, the resulting critical path is: *Start* → *Make ice tea* → *Prepare basket* → *Gather sports gear* → *Load car* → *Get gas* → *Drive* → *End* and the total estimated time is 50.

The main problem with the CPM is that the estimated time for each activity is given as reasonably accurate, but not always it is possible to know this variable with enough precision to make the estimate reasonably valid and accurate.

Program Evaluation and Review Technique (PERT)

The program evaluation review technique or PERT differentiate from the CPM as, for its estimate, take into consideration the uncertainty with the implementation of the probability field inside its model.

Differently form the CPM in this model the duration of a generic activity is represented by three different variables:

- Pessimistic time;
- Most likely time;
- Optimistic time.

As intuitable from the name, for pessimistic time is obtained by taking into consideration the worst possible scenario. Vice versa, the optimistic time is obtained from the best possible scenario. Lastly, the most likely time is the most probable duration for that certain activity.

This model bases its estimate upon five different, but fundamental, assumptions.

Assumption 1 – The gap between the pessimistic estimate and the optimistic estimate is 6 standard deviations.

Assumption 2 – The probability distribution for each activity, under the time variables, can be approximated to a beta distribution.

Assumption 3 – The activity times are statistically independent random variables.

Assumption 4 – As an approximation, assume that the critical path based on the expected time always required a longer total time in comparison with any other path.

Assumption 5 – The probability distribution of the total projected time lies under a normal distribution.

As a consequence of the first and second assumption, the standard deviation and the expected time of an activity can be calculated with the two following formulas:

$$\sigma^2 = [\tfrac{1}{6}(To - Tp)]^2 \rightarrow \sigma = \frac{To - Tp}{6}$$

$$Te = \tfrac{1}{3}\left[2Tm + \tfrac{1}{2}(Tp + To)\right] = \frac{1}{6}To + \frac{4}{6}Tm + \frac{1}{6}Tp$$

Note that: Te = Estimated time; Tm = most likely time; To = optimistic time; Tp = pessimistic time.

To conclude, the last assumption, in which the probability distribution is assumed similar to a normal distribution, open the useful possibility to calculate the probability of exceeding or not the final deadline through the use of a Z formula.

$$Z < \frac{X - \mu}{\sigma}$$

Note: X = exceeding time; μ = total estimated time; σ = total estimated variance

Before leaving the discussion about networks it is useful to analyze some strength and weakness point of the PERT-CPM approach form a managerial point of view. The next series of points are adapted from: Roman Daniel D., Managing Projects: a systems approach.

Strengths – The first strength point associated with this procedure is that to run efficiently a PERT-CPM analysis needs a project staff that carefully and methodically plan each step of the process, this obviously leads to a reduction of the total risk associated the project. Consequently, in a low-risk environment, each time and cost estimate are more accurate with a great improvement of the reliability of the project.

Lastly, the staff associated with the process can improve the control over low-risk complex project. As the mole of information connected with this type of project can easily overload the project manager, leading to information loss.

Weaknesses – In the presence of high-risk project, the estimates tend to be very imprecise leading to incorrect estimates and evaluation about it. Another weakness is that the enormous amount of information and the rigorous procedure of a PERT-like approach could easily lead to a false sense of security and precision to the project team. Moreover, in a scenario where the project is relatively small, the maintenance of this type of system can be a burden for the project as it is highly resource-consuming and a small team could not always afford it.

2.3.3. Queuing problems

The queuing problems are a particular category of problems in which some sort of waiting line is involved in a process. In a waiting line there are two different forces that push and pull the cost balance. On one hand, there is the cost of the activity that has to be provided to the units in queue, and, on the other hand, there is the effective waiting cost for the units in queue. As intuitable, it is necessary a balance between the two sources of cost with the final purpose of offering the activity in the most cost-efficient way. Note that the meaning of "cost" in the previous sentence is intended in a wider way (e.g. Social cost).

Once the necessary premises are made, it is now possible to define the basilar elements that compose a queue. "A 'Queue' is a waiting line of units demanding service at service facility (counter), the unit demanding service is called 'customer' and the device at which or the person by whom it gets served is known as the 'server'."[50]

In every queue system is possible to outline three common groups of characteristics:

- Input process;
- Service mechanism;
- Queue discipline.

Input process – the input process is composed by the union of all the internal and external variables that leads to enter into the queue.

[50] Moder Joseph J., Elmaghraby Salah E., Handbook of Operations Research: foundations and fundamentals, Litton Educational Publishing, Inc., 1978, pg. 352.

Service mechanism – The service mechanism, as intuitable, represents the way in which the service is offered to the customer. Some of the variables involved are, as an example, the number of servers, the duration of the service.

Queue discipline – The queue discipline defines the logic behind which the customers in a queue are served. FCFS (first-come, first-served) and FCLS (first-come, last-served) can be two intuitive examples.

Note that, as the main purpose of this thesis is to analyze the decision-making process form a managerial point of view, the purely mathematical aspect of the queue theory will not be discussed in this sub-paragraph.

The following discussion about decision-making in queue systems is adapted from: Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research.

Usually, from a managerial perspective, the design of a queuing system involves three main decisions:

- Number of servers at the facility (s);
- Efficiency of the servers (μ);
- Number of service facility.

These decisions are commonly shaped by three important variables. The first two of them (s, μ) are already defined in the previous list. Instead, the third one, that is not defined in the previous list, is the mean arrival rate for each facility (λ).

For a business, the two forces, previously defined in the introduction, can be renamed as:

- Cost of service;
- Cost of waiting.

Cost of service – For cost of service is intended the cost of the activity offered in comparison with the level of service offered. Mathematically defined as *E(SC)* it is internally composed by the tree previous variables (s, μ, λ).

Cost of waiting – For cost of waiting is intended the (monetary and non-monetary) cost of the units that are waiting for the activity in comparison with the level of service offered. Mathematically defined as *E(WC)*.

Consequently, the objective of a manager working on the queue can be mathematically defined with the next formula.

$$Min\ [E(TC) = E(SC) + E(WC)]$$

Note that E(TC) denote the function of the total cost.

In the analysis of the previous two definitions, it is easy to notice that expressing the correct mathematical representation of *E(WC)* is not an easy task in comparison to the *E(SC)*. This is due to the fact that the waiting costs are also correlated with non-monetary components.

A common way to resolve this particular problem is to translate the non-monetary terms in monetary one. As an example, a possible solution can be translating the waiting time in loss of productivity in the scenario in which the customers are people that work internally for a company.

There are two different forms to formulate mathematically the *E(WC)*:

- *g(N)* form;
- *h(W)* form.

g(N) form

The *g(N)* form is typically used in a scenario where the customer entity can be clearly defined as it is internal to the organization that provides the queue system. In this situation it is possible to associate directly the waiting cost for each unit of time spent in the queue to the number of customers *n* that enters in the queue.

As the results of the internal scenario, N can be considered a discrete random variable and consequently the cost expression can be defined as follow.

$$E(WC) = E\big(g(N)\big) = C_w \sum_{n=0}^{\infty} nP_n = C_w L$$

[51]Note that: C_w is the waiting cost associated with each unit of time, P_n is the probability associated with a particular queuing system.

***h(W)* form**

Differently from the *g(N)* form the *h(W)* form have the purpose to outline the *E(WC)* in a scenario where the customer is external from the queuing system provider. In this scenario, it is no more possible to correlate the waiting cost for unit of time to the total number of customers, as, in this case, the total waiting cost increase proportionally with the total time that each customer has to wait.

In this external scenario W is defined as a continuous random variable and consequently the cost expression can be defined as follow.

$$E(WC) = \lambda E\big(h(W)\big) = \lambda \int_0^{\infty} h(w) f_W(w)\, dw$$

[52]Note that: $f_W(w)$ is the probability density function of W.

[51] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 739.
[52] Hiller S. Fredrick, Lieberman Gerald J., Introduction to Operations Research, McGraw-Hill Inc., 1995, pg. 741.

Note that, in the previous formula *E(h(W))* is multiplied by λ (mean arrival rate at each facility), as *E(h(W)*) defines only the correlation between the waiting cost for a single customer and its total waiting time.

2.4. Decision analysis theory

"[…] much of business decision making takes place under conditions of uncertainty. Frequently we must take decisions with incomplete knowledge or knowing that the outcomes of these decisions are at best uncertain. While there is no magic solution for the dilemma facing a manager in these uncertain situations, there are ways of examining these decision problems that can help clarify how decisions can be made" [53].

As intuitable from the previous quote, in this paragraph a slight shift towards the managerial perspective is made. The main purpose of the following sub-paragraphs is to analyze and define the role of risk and uncertainty from a mathematical point of view.

In the decision analysis it is possible to outline four different phases:

- Alternatives identification;
- Future events identification;
- Pay-off evaluation;
- Alternatives evaluation and comparison.

Notice the similarities between these four phases and the elements of decision making defined in the first chapter, as a matter of facts, this definition is more mathematically oriented than the one previously encountered.

[53] Wisniewski Mik, Quantitative Methods for Decision Makers, Pitman Publishing, 1994, pg. 141.

Alternatives identification

The purpose of the first phase is to outline and enumerate all the possible alternatives from which a decision maker can face off. Note that this group of alternatives should contain also the possibility to abandon the project.

$$D_i \qquad i = 1, 2, \ldots, m$$

Note: D_i = Decision to alternative *i, m* = number of possible alternatives.

Future events identification

"[…] è necessario determinare quali siano gli eventi futuri, che indicheremo con il termine stati di natura, che possono influenzare gli effetti conseguenti alle diverse decisioni. Da un punto di vista probabilistico, si suppone che gli stati di natura costituiscano un insieme di eventi composti esaustivi e mutuamente esclusivi" [54] In other words, the goal of this phase is to define all the possible variables that can influence the course of time after the decision.

$$\bigcup_{j=1}^{n} S_j = S$$

Formula subject to restrictions:

$$j = 1, 2, \ldots, n$$

[54] Vercellis Carlo, Modelli e Decisioni: strumenti e metodi per le decisioni aziendali, Società Editrice Esculapio S.r.l., 1997, pg. 292.

$$S_j \cap S_k = \emptyset \qquad j \neq k$$

Note: S_j = state of nature j, n = number of total states of nature.

Pay-off evaluation

The third phase is to associate, for each couple *(D_i, S_j)* its profit *$V(D_i, S_j)$*. The process can be expressed in monetary or non-monetary terms.

Alternatives evaluation and comparison

Lastly, the alternatives evaluation and comparison phase, has, as a main purpose, the definition of an evaluation criterion *$f(V)$* used to define the best combination profit. Usually it corresponds to the maximization or minimization of that evaluation criterion function.

2.4.1. Uncertainty element

In a scenario where uncertainty cannot be neglected, where, moreover, it is not possible to use the probability as an instrument to evaluate the future events, it is possible to define three common evaluation criteria:

- Maximax criterion;
- Maximin criterion;
- Minimax regret criterion.

Maximax criterion

The Maximax criterion consists in the most optimistic vision about the project, as a matter of fact, the ratio behind this criterion is to choose the possibility that maximize the profit between the maximum pay-off for each alternative.

$$f(V) = \max_{i=1,2,\dots m} \max_{j=1,2,\dots n} V(D_i, S_j)$$

The following table represents an example of pay-off table for the Maximax criterion. The chosen decision is C as it maximize *f(V)*.

Decision	Future sales level (million $)			*f(V)*
	Low	Medium	High	
A	-5	8	10	10
B	1	5	9	9
C	-1	3	15	15

Table 11 Example table of Maximax criterion

Maximin criterion

Differently from the Maximax criterion, the Maximin criterion firstly outlines the worst-case scenario, where the possible outcome is the minimum possible pay-off for each alternative. Then the optimal decision chosen is the one that have the highest possible worst-case outcome.

$$f(V) = \max_{i=1,2,\dots m} \min_{j=1,2,\dots n} V(D_i, S_j)$$

The following table represents an example of pay-off table for the Maximin criterion. The chosen decision is B as it maximize *f(V)*.

Decision	Future sales level (million $)			*f(V)*
	Low	Medium	High	
A	-5	8	10	-5
B	1	5	9	1
C	-1	3	15	-1

Table 12 Example table of Maximin criterion

Minimax regret criterion

The last criterion discussed in this sub-paragraph is the Minimax criterion, in which, the logic behind the decision, is to minimize the maximum opportunity loss. Consequently, the chosen decision is the one that have the lower maximum exit cost.

$$\mathrm{L}(D_i, S_j) = [\max_{i=1,2,\ldots m} \mathrm{V}(D_i, S_j)] - \mathrm{V}(D_i, S_j)$$

$$f(V) = \min_{i=1,2,\ldots m} \max_{j=1,2,\ldots n} \mathrm{L}(D_i, S_j)$$

Note: $\mathrm{L}(D_i, S_j)$ = opportunity loss for the combination (D_i, S_j)

The following table represents an example of pay-off table for the Minimax criterion. The chosen decision is B as it minimize *f(V)*.

Decision	Future sales level (million $)			$f(V)$
	Low	Medium	High	
A	15	2	0	15
B	8	4	0	8
C	16	12	0	16

Table 13 Example table of Minimax criterion

2.4.2. Risk element

"[…] Compare a roll of a die against the production decision for a brand-new and truly innovative product. In the first case we do not know which number will be drawn, and betting on it means making a risky decision. However, we have no doubt about the rules of the game. […] In the second case, we don't even know the probability distribution, which will be more subjective than fact-based. In extreme cases even the use of probabilities is questionable."[55] In other words, the main difference between the concept of uncertainty and risk, is the presence or not of a more or less objective structure that dictate the likelihood of a particular event.

In this scenario it is possible to associate to each state of nature a specific probability that follows the next rule.

$$\sum_{j=1}^{n} P(S_j) = 1$$

[55] Brandimarte Paolo, Quantitative Methods: an introduction for business management, John Wiley and Sons, Inc., 2011, pg. 693.

Formula subject to restrictions:

$$j = 1, 2, \ldots, n$$

$$P(S_j \cap S_k) = 0 \qquad j \neq k$$

It is now possible to analyze three different criteria which purpose is to evaluate a decision in an environment subject to risk.

- Monetary expected value;
- Expected value of regretted opportunities;
- Expected value of perfect information.

Monetary expected value

The first method, as intuitable from the name, consists in the evaluation of the expected mean monetary return for each possible alternative. The optimal monetary decision can be obtained with the following formula.

$$MEV(V^*) = \max_{i=1,2,\ldots m} \sum_{j=1}^{n} P(S_j)\,\mathrm{V}(D_i, S_j)$$

Note: $f(V^*)$ = Optimal monetary expected value

The following table represents an example of pay-off table for the monetary expected value criterion. The chosen decision is A as it maximize *MEV(V)*.

Decision	Future sales level (million $)			$MEV(V)$
	Low	Medium	High	
A	20	30	40	29
B	13	17	38	21.2
C	3	7	22	10.4
$P(D_j)$	0.2	0.5	0.3	

Table 14 Example table of monetary expected value criterion

Expected value of regretted opportunities

Similarly to the Minimax criterion, this particular criterion consists in the minimization of the opportunity loss for each decision. But, in this scenario each opportunity loss is weighted in proportion to its probability.

$$EVRO(V^*) = \min_{i=1,2,\ldots m} \sum_{j=1}^{n} P(S_j)\, \mathrm{L}(D_i, S_j)$$

Note: $EVRO(V^*)$ = "Optimal" expected value of regretted opportunities

Note that both the monetary expected value criterion and the expected value of regretted opportunities criterion leads to the same solution. This is due to the use of the same, but differently expressed, formulation for both criteria.

The following table represents an example of pay-off table for the expected value of regretted opportunities criterion. The chosen decision is A as it minimize *EVRO(V)*.

Decision	Future sales level (million $)			*EVRO(V)*.
	Low	Medium	High	
A	20	10	0	9
B	25	21	0	15.5
C	19	15	0	11.3
$P(D_j)$	0.2	0.5	0.3	

Table 15 expected value of regretted opportunities criterion

Expected value of perfect information

The expected value of perfect information or EVPI represents the price that the decision maker is disposed to pay to obtain the perfect information on the future events. This element is not a decision criterion by itself, but it can help in the hard evaluation of the perfect information scenario.

The EVPI can be calculated with the following formula:

$$EVPI = EMVPI - EMV(V^*) = EVRO(V^*)$$

Where, EMVPI (Expected Monetary Value of Perfect Information) is the sum of all the maximum monetary values obtained for each decision, if all the future events related with a decision are known and certain, and the best decision is always made.

$$EMVPI = \sum_{j=1}^{n} P(S_j)\, V_{max}(S_j)$$

To conclude, as the formula suggests, the EVPI for the previous example (table 14 and 15) is 9, as it is equal to *EVRO(V^*).*

2.4.3. Decision trees

Decision trees are a common and natural way to define problems under a risk environment. Tree diagrams have the purpose to define and show the logical progression of a risk problem decision after decision.

The next figure is the representation of a possible decision tree for a product launch problem.

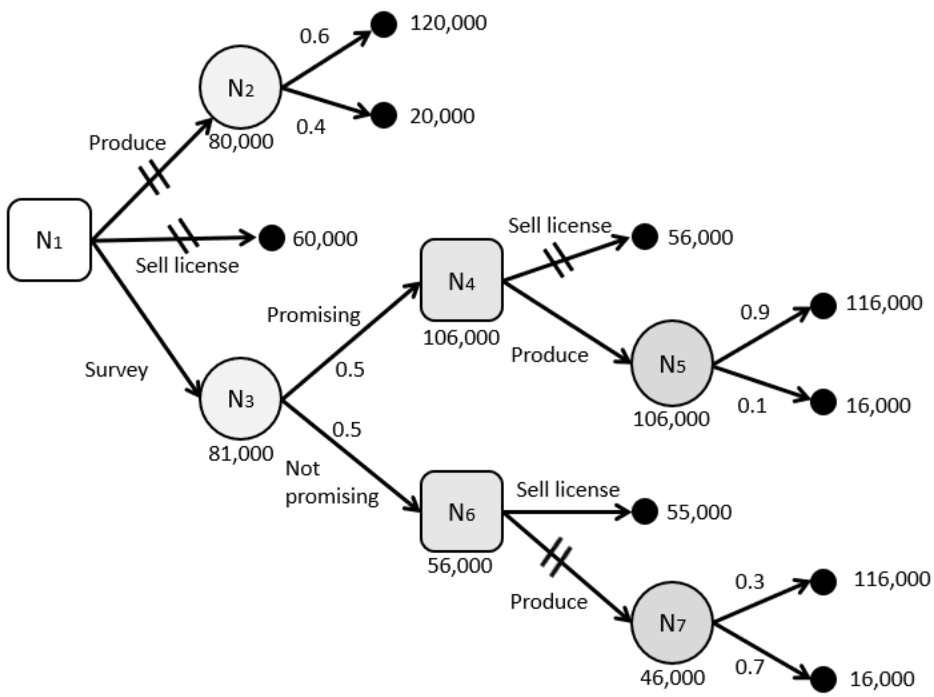


Figure 15 Example of decision tree for a new product launch [56]

[56] Brandimarte Paolo, Quantitative Methods: an introduction for business management, John Wiley and Sons, Inc., 2011, pg. 698.

As intuitable this type of representation is very useful in a scenario where the problem structure is sequential (concept already discussed in paragraph 1.1), and consequently every decision is connected with earlier decisions and/or outcomes.

Note that the mean of two oblique lines over an arrow is “not preferable alternative”.

As it is possible to see form figure 15, in a decision tree representation there are two main types of nodes:

- Decision nodes;
- Chance nodes.

Decision nodes

In a decision tree, a decision node corresponds to a discrete choice, made by the decision maker, between mutually exclusive alternatives. The graphical representation is a square.

Chance nodes

A chance node corresponds to a random natural outcome driven by a series of external, and usually uncontrollable series of events. A probability (value from 0 to 1) is associated with each alternative, and the sum of all the probability of a given chance is equal to 1. This particular node is represented by a circle in the decision tree.

Note that each of the risk criteria, discussed in the previous sub-paragraph, can be applied with this type of representation as each group of chance nodes, that follows a decision node can be represented as a pay-off table in risk condition.

Note also that, as this problem representation is based on probability, it is possible to apply the Bayes theorem whenever needed. This could improve the decision process in an enormous series of scenarios, moreover a comprehensive evaluation of all the possibilities is necessary.

$$P\left(S_j \middle| A\right) = \frac{P(S_j)P(A \mid S_j)}{\sum_{j=1}^{n} P(S_j)P(A \mid S_j)}$$

Note: S_j = one possible mutually exclusive event, A = generic event.

Note that the Bayes theorem and its formula will not be discussed in this thesis as it is given by known.

2.5. A brief analysis of Multi-Criteria Decision Making (MCDM)

Multi-criteria decision making can be represented as an evolution of the previous models, the fundamental logic behind this model category is to change the decision maker approach to the decision making, shifting from a distributive view point, to an integrative one. Note that for integrative point of view is intended a scenario where the decision maker can increase the total gain or "pie" by making a decision where multiple conflicting objectives are satisfied.

The next two quotes represent two slightly different interpretations on the meaning of Multi-Criteria Decision Making.

"A general definition of MCDM is the solving of a decision problems that involve multiple (generally conflicting) objectives" [57]

"MCDM is a word of concepts, approaches, models and methods to help the decision makers to DESCRIBE, EVALUATE, SORT, RANK, SELECT or REJECT objects (candidates, products, projects, and so on) on the basis of an evaluation (expressed by scores, values, preference

[57] Goicoechea A., Duckstein L., Zionts S., Multiple Criteria Decision Making: proceedings of the ninth international conference: theory and applications in business, industry, and government, Springer-Verlag, 1992, pg. 33.

intensities) according to several criteria. These criteria may represent different aspects of the teleology: objectives, goals, targets, reference values, aspiration levels, utility.”[58]

2.5.1. Multi-Criteria Decision Analysis (MCDA) aggregation models

As intuitable, the key purpose around the Multi-criteria Decision Making is to aggregate and unify different dimensions of the problem (or relations), each one connected with a different evaluation criterion, into a unique structure, making possible the comparison of all the possible alternatives.

In the decision-making literature there are plenty of multi-criteria decision models, the purpose of following list is to outline four popular one:

- AHP (Analytic Hierarchy Process);
- ELECTRE I;
- MAVT (Multi-Attribute Value Theory);
- TACTIC.

AHP

The Analytic Hierarchy Process “is designed when either subjective and objective measures or just subjective measures are being evaluated in terms of a set of alternatives based on multiple criteria, organized in a hierarchical structure”[59]

The structure of an AHP model is composed by three different layers:

- Goal;
- Criteria;

[58] Rodin E. I., De Buryn Chr., Colson G., Models and Methods in Multiple Criteria Decision Making, Pergamon Press plc, 1989, pg. 1201.
[59] Fox William P., Mathematical Modeling for Business Analytics, Taylor &Francis Group, LLC, 2018, pg. 147.

- Alternatives.

Goal – The goal represents the top layer of the model, as described in the first chapter, it defines the wanted final result for the decision maker.

Criteria – The mid layer is composed by the group of criteria that have to be evaluated and weighted.

Alternatives – The lower layer is composed by all the possible, presumably valid, alternatives, for each one it is necessary a measurement against each criterion.

The next figure represents a generic AHP hierarchy.

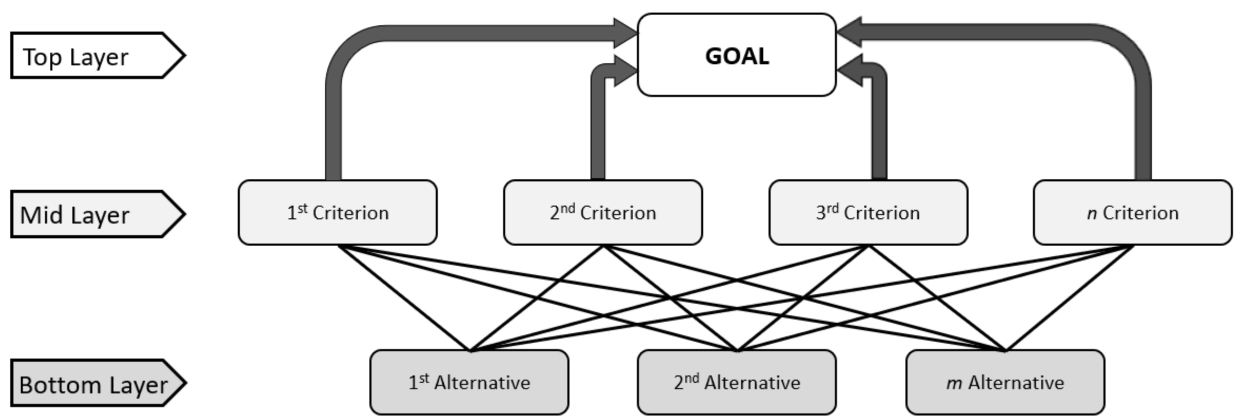


Figure 16 Example of generic AHP hierarchy[60]

The logic behind the assessment is to assign a score to each node (except for the bottom layer) on the basis of its contribution to the decision maker goal.

The score assignment procedure is composed by three steps, described as follow.

[60] Fox William P., Mathematical Modeling for Business Analytics, Taylor &Francis Group, LLC, 2018, pg. 148.

Step 1 – In the first step the various dimensions (criteria) of the problem are compared in a subjective manner, if it is possible to directly interpret the dimensions relations in a quantitative manner proceed directly to step 2. Usually this is done with different qualitative instruments such as: pairwise, relative importance, or semantic scale.

Step 2 – The qualitative assessment for each pairwise comparison attribute-alternative is translated in quantitative evaluation scale, from 1 (weak importance/connection) to 9 (strong importance/connection). This leads to the composition of an *n* x *n* pairwise comparison matrix.

Step 3 – The last step consists in the allocation of a score or weight w_i for each dimension. *"*the scores are computed as the eigenvector corresponding to the maximum eigenvalue of the matrix and are normalized to 1"[61] where for eigenvalue is intended any number such that a given matrix minus that number times the identity matrix has zero determinant.

The same procedure is used to compare each alternative for each dimension. The resulting score is defined as $a_i(x)$ where x represents an alternative. Lastly, the global score of an alternative, and consequently its comparison with other alternatives, can be calculated with the two following formulas.

$$Global\ score\ of\ alternative\ x = \sum_{i=1}^{n} w_i a_i(x)$$

$$x \succsim y \Leftrightarrow \sum_{i=1}^{n} w_i a_i(x) \geq \sum_{i=1}^{n} w_i a_i(y)$$

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[61] Bouyssou Denis, Marchant Thierry, Pirlot Marc, Tsoukias Alexis, Vincke Philippe, Evaluation and Decision Models with Multiple Criteria: stepping stones for the analyst, Springer Science + Business Media Inc., 2006, pg. 157.

ELECTRE I

The purpose of the ELECTRE I method is to aggregate performance tables into a choice set. Note that exists several variants of this method and the following representation is one of them.

This particular method is composed by three fundamental steps:

- Preference modelling;
- Aggregation;
- Exploitation.

Preference modelling – The preference modelling step consists in the definition of two binary relations S_i and V_i for each dimension with the help of the following formula.

$$a\, S_i\, b \iff g_i(a) \geq g_i(b)$$

$$a\, V_i\, b \iff g_i(a) > g_i(b) + \tau_i$$

Note: *a, b* are alternatives, τ_i is positive and represents a threshold.

The first formula says that *a* is better or equal to *b*, the second formula says that *a* is better than *b* plus a given threshold τ_i that assure the gap between *a* and *b*.

Aggregation –the aggregation step consists in developing an outranking relation on *a*, for which *a* outrank *b* if, and only if, *a* is better and sufficiently large than *b* and also if *b* is not too much better than *a* in any dimension. For this purpose, it is used the coefficient w_i which is an importance coefficient associated to each criterion. The sum of all these coefficients must be larger than a certain threshold *c* for *a* to outrank *b*.

The previous definition of outranking function converges in the following formula.

$$a \gtrsim (g, w, \tau, c) b \Leftrightarrow \sum_{i:\, aS_i b} w_i \geq c_i$$

$$\nexists i : bV_i a$$

Note: g = performance table, $w = (w_1, \ldots, w_n)$, $\tau = (\tau_1, \ldots, \tau_n)$.

Exploitation – As the outranking relation in this method is not a weak order, it is common to use the kernel (κ) of the relation $\gtrsim$. The kernel has the capacity to outline a sub-set of promising alternatives, but note that can not exist and does not necessarily contain the best alternative.

The kernel has two different properties. The first one is that each alternative not in the kernel is outranked by at least one alternative in the kernel, in this manner a better subset of alternatives is outlined. The second one is that no alternative in the kernel outranks any other alternative in the kernel.

MAVT

Differently from the previous two methods, the Multi-Attribute Value Theory methods is based on the study and evaluation of the preference relations. This method consists in the association of a coefficient u to the performance vector $x = (x_1, \ldots, x_n)$, where $u(x) = \sum_{i=1}^{n} u_i(x_i)$ and n are the dimensions, obviously the coefficient u_i is strictly correlated with the subjective preference evaluation of its alternative for that specific criterion. In other words, this method consists in the association of one value that outline the performance of one alternative, based on the sum of performance of that alternative for each criterion. In this manner it is possible to compare two or more different alternatives with the following formula.

$$x \succsim y \Leftrightarrow \sum_{i=1}^{n} u_i(x_i) \geq \sum_{i=1}^{n} u_i(y_i)$$

Note that only preferences that are independent weak orders (rankings, possibly where some members are tied with each other's) can be represented in such way.

TACTIC

The TACTIC method is very similar to the ELECTRE I, but in this case, there is a global performance relation instead of a choice set.

As intuitable, similarly to the ELECTRE I method, this particular method is composed by three fundamental steps:

- Preference modelling;
- Aggregation;
- Exploitation.

Preference modelling – For each dimension it is necessary to define two binary relations. The first relation expresses that a is better than b on a given dimension because its difference exceed a given threshold. The second relation expresses that a is much better than b on one specific dimension because it exceeds a threshold considered very large.

The following formulas represent these two relations

$$a\, P_i\, b \Leftrightarrow g_i(a) - g_i(b) \geq \tau_{i,1}$$

$$a\, V_i\, b \iff g_i(a) \geq g_i(b) + \tau_{i,2}$$

Note: *a, b* are alternatives, $0 \leq \tau_{i,1} < \tau_{i,2}$.

Aggregation – Similarly to the ELECTRE I method an outranking binary relation is constructed on a. "We will consider a outranks b if the coalition of criteria such that a is better than *b* is sufficiently larger than the coalition of criteria such that *b* is better than a and if *b* is not much better than *a* on at least one dimension."[62] As usual it is necessary to define an importance coefficient w_i associated to each criterion. Lastly, the importance of a given coalition of criteria is equal to the sum of each importance coefficient associated with each criterion represented in the coalition.

The previous definition of outranking function converges in the following formula.

$$a \succ (g, w, \tau, c) b \iff \sum_{i:\, aP_i b} w_i \geq p \sum_{i:\, bP_i a} w_i$$

$$\nexists i : bV_i a$$

Note: g = performance table, $w = (w_1, \ \ldots, \ w_n)$, $\tau = (\tau_{1,1}, \ \ldots, \tau_{1,n}, \tau_{2,1}, \ \ldots, \tau_{1,n})$. p is a threshold.

Exploitation – Note that as the outranking relation is usually not represented in a weak form the interpretation of the result is harder in comparison of the similar ELECTRE I.

[62] Bouyssou Denis, Marchant Thierry, Pirlot Marc, Tsoukias Alexis, Vincke Philippe, Evaluation and Decision Models with Multiple Criteria: stepping stones for the analyst, Springer Science + Business Media Inc., 2006, pg. 166.

CHAPTER 3

Management decision making

3.1. Decision making process

"We live in a culture of decision-making"[63]. The purpose of this chapter is to analyze the decision-making environment form the point of view of the decision-maker. A greater emphasis will be placed on the human essence of the decision maker, as a single person, or more commonly as a group composed by multiple entities with different biases.

Differently from the first chapter, the process proposed in the following sub-paragraphs can be seen as a multifunctional swiss knife to solve problems, from the simplest to the more complex ones.

The next series of sub-paragraphs are adapted from the book: Chevallier Arnaud, Strategic Thinking in Complex Problem Solving.

3.1.1. Ideological path of decision-making process

The process proposed in this paragraph is one of the numerous problem-solving processes existing in literature.

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[63] Prof. Warglien Massimo, Ca' Foscari, Venezia, 2019

This particular process for problem-solving can be divided into four different steps:

- Frame the problem;
- Diagnose the problem;
- Find potential solutions;
- Implement the solution.

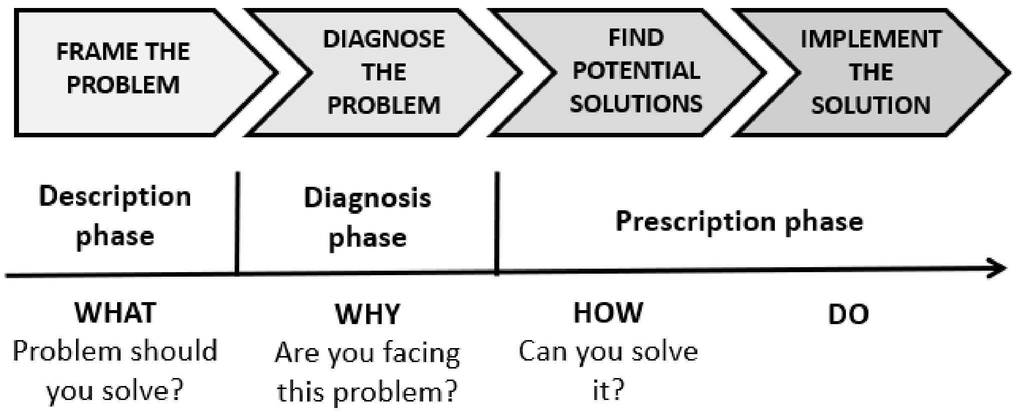

Figure 17 Four steps of the problem-solving approach [64]

Note that usually all the mathematical models discussed in the second chapter are located in the third, and sometimes the second, step.

WHAT

The first step of this problem-solving process, is composed by the problem framing. Here the main objective is to identify the real problem. This can be helpful as, sometimes, it is possible to unconsciously shift the solution out of the real context, with the result of finding a possibly good solution but not for the correct problem.

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[64] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 2.

WHY

The second step consists in the diagnosis of the problem, with the purpose of discover all the plausible sources, or root causes, of the problem, and then identify the actual one. In this manner it is possible to generate a better solution, and also it is possible to avoid the recurrence of the problem.

HOW

In the third step a series of possible solutions (called also alternatives) to the problem are defined, then it is possible to move toward the effective decision-making stage, where the decision-maker defines the best possible solution form the pull of possible alternatives.

DO

Intuitively, the last step consists in the implementation of the chosen solution. Obviously, it is also necessary to monitor the implemented solution, as it is possible to have some unknown, and moreover unwanted side effects.

The following five key guidelines are adapted from the book: Chevallier Arnaud, Strategic Thinking in Complex Problem Solving.

The following list represents five useful principles to bear in mind in the entire decision process:

- Use divergent and convergent thinking;
- Use issue maps;
- Acquire the right skills;
- Simplify to reveal the underlying structure;
- Do not fool yourself (and others).

Use divergent and convergent thinking

In every step of the previously described process it is very useful to apply both divergent and convergent thinking, as “Diverging, you think creatively: stretching your mind to identify new patterns. Converging, you think critically: gathering data to analyze each possibility, compare it with others, and select the best."[65]

Use issue maps

The central tools around the methodology proposed in the next series of sub-paragraphs are the issue maps. Graphically, issue maps are very similar to the representation of a decision tree, but in this case, the pool of possible solution for the problem can also be "unconventional" and moreover there's no probability involved. This tool will be discussed deeply in the following pages.

Acquire the right skills

Another valid tip, useful in the problem-solving process, is to acquire the right set of skills able to improve the efficiency and effectiveness of the decision-making process. Note that, in the skills category, both classical and transversal skills are present, required, and needed.

Simplify to reveal the underlying structure

The definition of this tip is very intuitive, simplicity is central in the problem-solving process, as it is easier to find solution to simple, well understood, and basilar problems. This tip is applied perfectly in the framing step, where the purpose of framing the problem is to reveal its basilar structure, making possible a parallel and/or sequential approach.

Do not fool yourself

The last tip given by the author of the book is to be aware of the human being. As already discussed in the first chapter, humans are heavily biased and can be easily influenced by almost everything. In the entire problem-solving process, it is always necessary to keep an eye on this particular condition, as it is able to deviate the decision maker from a better solution to a worst one.

[65] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 9.

3.1.2. Problem framing

The first, and most important, step towards a good decision is the problem framing. This step is composed by the framing of the two following phases:

- Description phase;
- Diagnosis phase.

Note that the framing of the diagnosis phase is useful for the group of arguments that will be discussed in the following sub-paragraph.

Description phase framing

In the description phase, the frame of the project is defined. This can be done with the help of a simple but useful instrument called problem definition card or also “what card”.

The next table is an example for the template of a what card.

<table>
<tr><td>Project name:</td><td colspan="5"></td></tr>
<tr><td>Specific goals: (what are you going to do)</td><td>Your main objectives.</td><td>Out of scope: (what you are not going to do)</td><td colspan="3">Things that could be included in the project but you have decided to leave out.</td></tr>
<tr><td>Decision maker(s):</td><td>Person(s) with the formal authority to decide the direction of the project, including killing it.</td><td>Other key stakeholders:</td><td colspan="3">Persons who do not have formal authority but can influence the scope and the outcome of the project or will be impacted by it.</td></tr>
<tr><td rowspan="7">Timetable:</td><td colspan="3">Actions</td><td>Needed time</td><td>Cumulative time</td></tr>
<tr><td colspan="3">1. Frame the problem (define the WHAT).</td><td></td><td></td></tr>
<tr><td colspan="3">2. Diagnose the problem (find the WHY).</td><td></td><td></td></tr>
<tr><td colspan="3">Define the diagnostic question and identify possible causes.</td><td></td><td></td></tr>
<tr><td colspan="3">Collect the diagnostic evidence, analyze, and draw conclusions.</td><td></td><td></td></tr>
<tr><td colspan="3">3. Identify solutions (find the HOW).</td><td></td><td></td></tr>
<tr><td colspan="3">Define the solution key question and identify possible solutions.</td><td></td><td></td></tr>
</table>

	Collect evidence, analyze, and decide which solution(s) to implement.		
	4. Implement (DO).		

Resources:	Resources (money, people, equipment, etc.) that you dedicate to the project and for who long.

Possible problems:	Things that can go wrong.	Mitigation actions:	Initiatives to proactively defuse the possible problems.

Table 16 What card template [66]

As it is possible to notice from the template, the what card is pretty exhaustive form the problem point of view, it summarizes all the information needed to avoid misalignment with the wanted goal.

Project name – The first row should contain a descriptive title for the project that has to be solved. Note that it is mandatory to have clearly in mind what the problem is, as it shapes all the steps of the process.

Specific goals/Out of scope – The second row or "Specific goals/Out of scope", has the important purpose of outlining the boundaries of the possible alternatives. Here it is necessary to write what are the most valid steps definition (WHY, HOW, DO) for the problem outlined, but it is also necessary to write the steps definition of what we do not want to find or answer. In this manner a series of boundary lines for the problem are traced.

Decision maker(s)/Other key stakeholders **–** Intuitively, in the third row it is necessary to outline who is the decision maker, but more importantly, who are the other stakeholders involved in the project. This need to be done as these stakeholders are directly or indirectly influenced by the project, and sometimes they can also influence the decision-maker in the decision process.

[66] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 22.

Timetable – Similarly to the AON approach in the network problem paragraph, the timetable row has the purpose to define the average time needed for each action involved in the process.

Resources – In this row it is necessary to write all the monetary and non-monetary resources needed for the project. As always, every resource in this world is scarce and can be useful in various different activities (not only for the specific project), so an eye on the cost side trade-off is needed.

Possible problems/Mitigation actions – The last row in the what card is dedicated to the definition of the possible series of problems and solutions that can be encountered during the project. This row is important as it not only helps with a reduction of the risk incurred in the problem solution, but also helps the decision maker to have a more realistic and concrete approach to the entire problem.

Diagnosis phase framing

In the diagnosis phase the frame of the diagnosis is defined. An important task in the diagnosis phase is the creation of an introductory flow.

The introductory flow is composed by three different elements:

- Situation;
- Complication;
- Diagnostic key question.

Situation – The situation element has the purpose of defining the portion of universe interested by the defined problem. Note that the definition of the situation should follow some important guidelines (i.e. the presence of only the necessary and sufficient information, the presence of only positive information, be concise, etc.).

Complication – The second element of the introductory flow is the complication. This element has the purpose to outline and define the particular problem encountered for the previous specific situation. Note that there should be only one central complication supported by one or several components.

Diagnostic key question – the last element that plays a central role in the introductory flow is the diagnostic key question. This particular question must be able to answer at the "why" in the relation between situation and complication. A key question can be considered good when it is able to encompasses all the others relevant questions (graphically speaking it can be mentally represented as the origin of a tree diagram).

Note that, in general, a key question should be centered around the right topic. This because the topic has a central role in the definition of the solution space for the problem. As a matter of facts, a topic too narrow restricts too much the solution space with the possible exclusion of valid solutions. Contrary, a topic too broad can be an obstacle as it makes hard to evaluate all the alternatives.

Once create an introductory flow it is possible to summarize the entire diagnostic frame in a "why card" to have always a referral point as regards the diagnosis phase.

The following table is an example of template for a why card.

Situation:	The information that is necessary and sufficient to specify which part of the universe are you considering. Only the necessary information. This information should be positive (i.e., there is no problem at this stage) and undisputed (i.e. reasonably familiar with the setting agree with it)
Complication:	The one problem in that part of the universe; that is, the unique need for change (potentially illustrated by one or several of its symptoms/consequences)
Diagnostic key question:	The one diagnostic question that you want to answer. It 1. Is phrased as "why…?" 2. Addresses an appropriate topic 3. Has an appropriate scope 4. Has an appropriate phrasing

Decision makers:	The person(s) who have the formal authority to direct your project/authorize your recommendation
Others stakeholders:	The person(s) who do not have the formal authority but who can influence the project
Goals and logistics:	Budget, deadlines, types of documents, quantitative objectives, etc.
Voluntarily left-out answers (things that we could do but we decide not to)	The actions under your control that you choose not to take

Table 17 template for a why card[67]

Note that some of the elements contained in the what card are proposed again here, this is done to have always all the key information needed in the same place.

3.1.3. Problem causes definition

Once framed the diagnosis phase, the following step consists in the definition of the causes that generate the problem subject of analysis. In this and the following steps the main role is played by a fundamental instrument called issue map.

An issue map is composed by the following two elements:

- Diagnostic maps;
- Solution maps.

Before discussing the previous two elements it is mandatory to outline the four basic rules of an issue map.

The following figure is a graphical representation of these four rules.

[67] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 42.

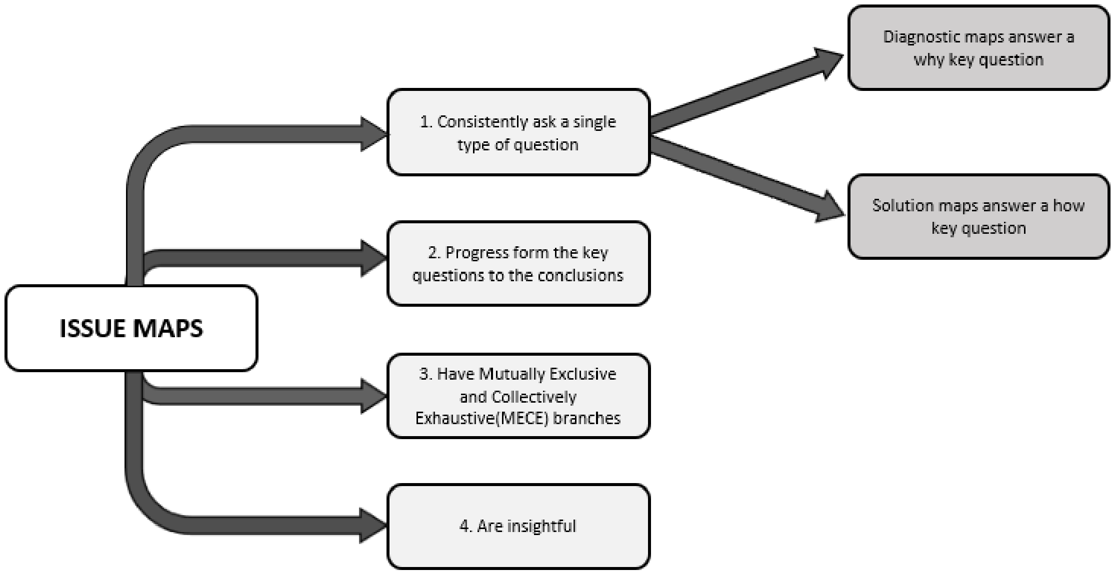

Figure 18 Basic rules for an issue map [68]

Note that both of the maps should follow these rules, note also that as the four rules are pretty straightforward a deep description is not needed.

Diagnostic maps – A diagnostic map has two different objectives. The first one is to define in details the key question, breaking it in sub part increasingly more detailed, with the goal of revealing the specific structure of the question. The second objective is to provide a pull of possible hypothesis for all the possible groups of root causes.

[68] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 48.

Solution maps – The solution map can be considered the complementary instrument of the diagnostic map, Intuitively form the name, its purpose is to outline a series of possible solutions for the problem. Note that this argument will be discussed in the next sub-paragraph.

Once defined the basis it is possible to continue with the discussion about the main topic. The second step of the problem-solving process consists in the definition and identification of the causes responsible in the generation of the problem.

This step is composed by two sequential elements:

- Identification of potential causes;
- Identification of actual causes.

Identification of potential causes

In the first part of the problem definition all the potential root causes for the main problem are defined. The following figure is an example of diagnostic map applied in the context of the identification of the potential causes.

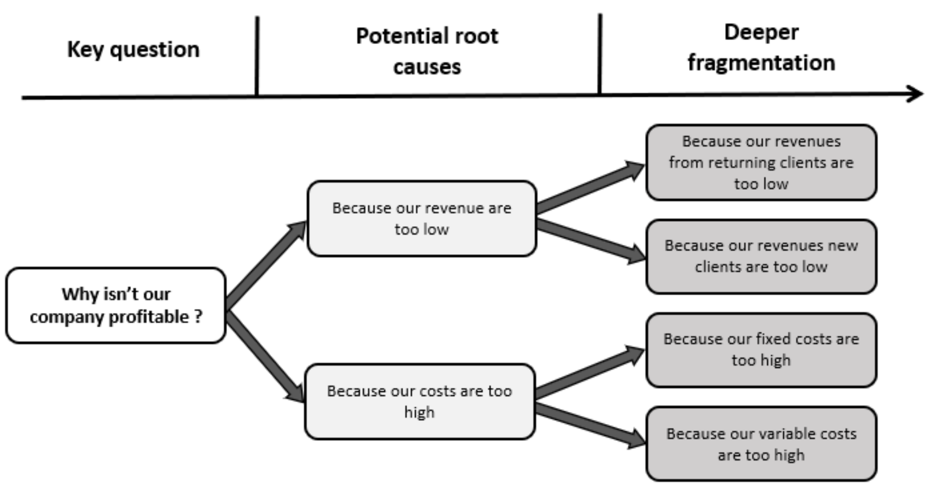

Figure 19 example of a partial diagnostic map [69]

[69] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 60.

It is necessary to notice some important concepts. Firstly, note that the previous figure represents a very simplified scenario, usually there can be more than one fragmentation step. Secondly note that each box, with the exclusion of the key question, represent a potential root cause and it can be solved by the same solution given by the solution map, or by a different one.

Identification of actual causes

Once identified the potential causes the next step toward the final result is to generate a series of hypothesis for each group of root causes.

The following figure is the continuum of the example of figure 19.

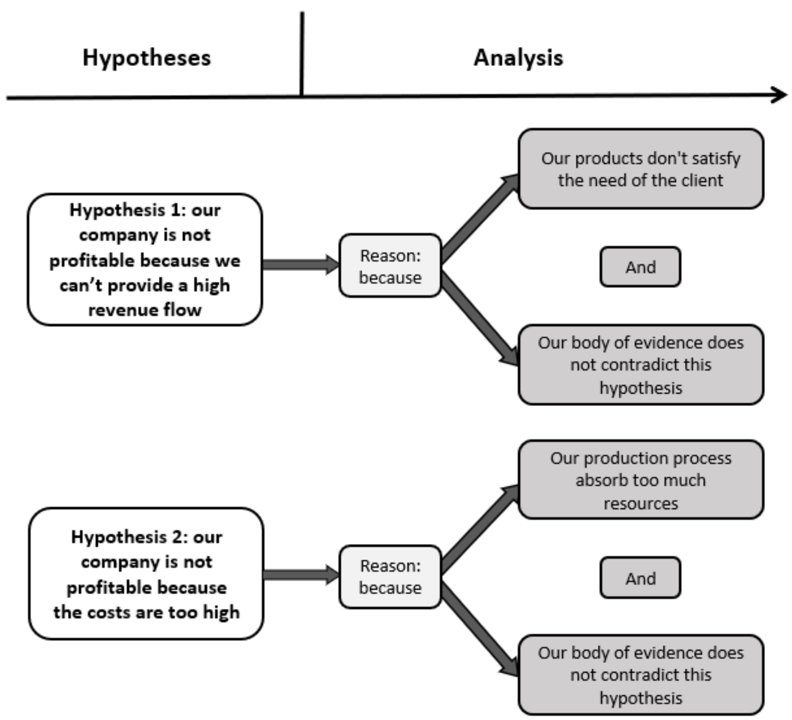

Figure 20 Identification of actual causes in the diagnostic map of figure 19

Note the generation of two macro categories of potential root causes as each hypothesis satisfy both the potential root cause and its fragmentation. Note also that the second reason for each hypothesis has the purpose of improving the identification of the actual causes.

It is now possible to have the complete diagnostic map for the scenario presented in figure 19. Obviously, the choice for the correct hypothesis depends on the validity or not of its outlined "reasons".

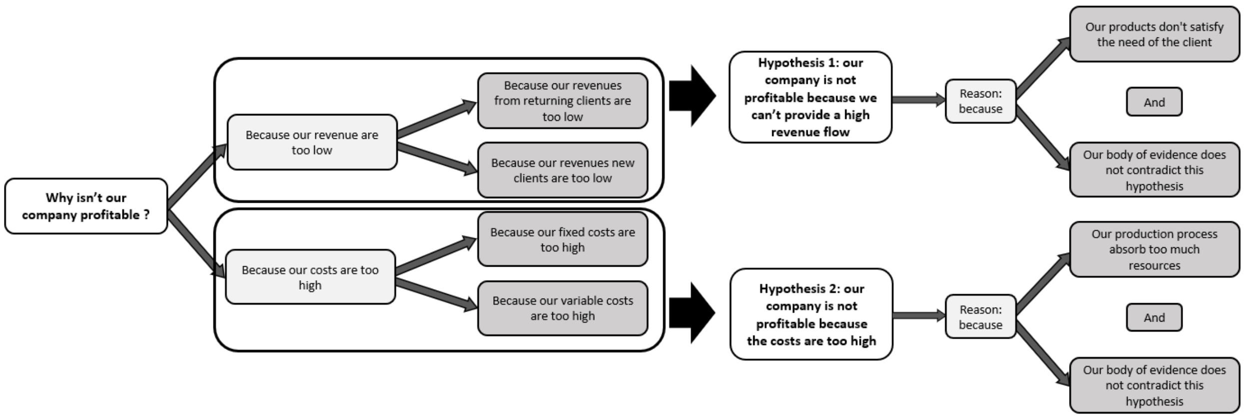

Figure 21 Complete diagnostic map for the scenario of figure 19

Before concluding this sub-paragraph, it is useful to mention the use of the Bayesian inference as it results very helpful in a situation where convergent thinking is prevalent in a problem-solving process.

Bayesian inference "allows you to revise your original estimate of how likely a hypothesis is (called your prior probability or prior) in light of a new item of evidence to get a posterior probability or posterior to the hypothesis" [70]. Intuitively form the name and the previous quote, the Bayesian inference consists in the association of a subjective, but pondered, probability on each hypothesis. In this manner the application of the Bayes' Theorem (defined at the end of the previous chapter) become a possibility, and moreover a useful instrument to evaluate the probability of each root cause path.

[70] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 104.

3.1.4. Alternatives definition

The third step of the problem-solving process consists in the definition and identification of the group of alternatives for the main problem.

Before starting with the argument, it is useful to introduce a new instrument called "how card". Notice that as the form of the how card is pretty similar to the one of the why card (discussed at the beginning of the chapter), the content changes with the advancement on the problem.

The following table is a guideline example for a how card.

Situation:	The information that is necessary and sufficient to specify which part of the universe are you considering. Only the necessary information. This information should be positive (i.e., there is no problem at this stage) and undisputed (i.e. reasonably familiar with the setting agree with it)
Complication:	The one problem in that part of the universe; that is, the unique need for change (potentially illustrated by one or several of its symptoms/consequences)
Solution key question:	The one diagnostic question that you want to answer. It 1. Is phrased as "how…?" 2. Addresses an appropriate topic 3. Has an appropriate scope 4. Has an appropriate phrasing
Decision makers:	The person(s) who have the formal authority to direct your project/authorize your recommendation
Others stakeholders:	The person(s) who do not have the formal authority but who can influence the project
Goals and logistics:	Budget, deadlines, types of documents, quantitative objectives, etc.
Voluntarily left-out answers (things that we could do but we decide not to)	The actions under your control that you choose not to take

Table 18 Example guideline for a how card [71]

[71] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 118.

As said before, the main protagonist for this step is the composition of a solution map. (already defined in the previous sub-paragraph).

Similarly to the previous step, the alternatives definition is composed by two sequential sub-steps:

- Identification of potential alternatives;
- Selection of the best alternative.

Identification of potential alternatives

As regards the identification of potential alternatives, the process of construction for the solution map follows the same path and also rules of the one for the diagnostic map. The map is composed by one key question and a series of potential MECE (Mutually Exclusive and Collectively Exhaustive) alternatives that can be successively fragmented in MECE sub-units.

The next figure represents an example of solution map.

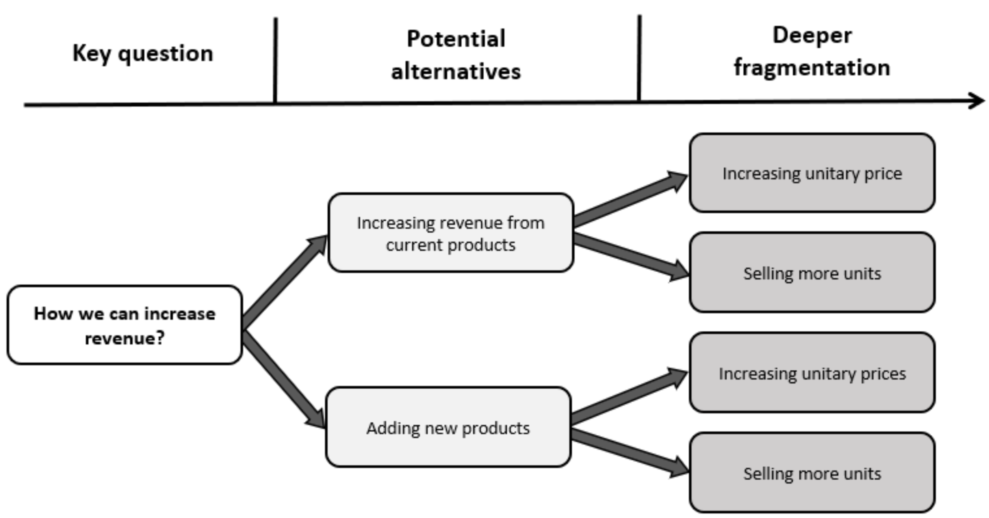

Figure 22 Example of a partial solution map [72]

[72] Chevallier Arnaud, Strategic Thinking in Complex Problem Solving, Oxford University Press, 2016, pg. 133.

In the previous example it is possible to outline 2 alternative groups. The first one is to increase the revenue of the current product. The second one is to push in the market newer products.

Selection of the best alternative

Once defined all the potential alternatives, the following sub-step is to outline for each group of alternatives a hypothesis for its suitability. The following figure is the continuum of the example of figure 22.

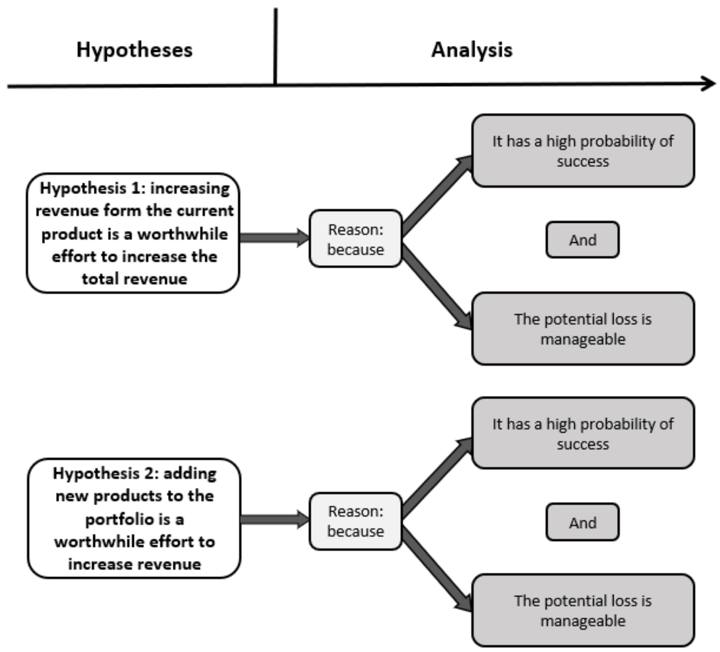

Figure 23 Identification of the actual alternatives for the solution map of figure 22

Note that the previous example represents a simplified vision of the hypothesis. This because its main purpose is to give an idea of the composition of a solution map.

The first action towards the selection of the best alternative starts with the removal of the unsuitable ones. This process consists in the research, for each fragmentation of the hypothesis, of evidences that can confirm or disconfirm our hypothesis.

Note that not all evidences are equally trustworthy, consequently it is necessary to pounded every decision that involves this type of instrument.

Once removed the unsuitable alternatives an objective comparison of the performance for each residual alternative is needed, it is here that the effective decision-making action is made.

In this scenario, a valid and useful instrument able to improve the decision-making process is the SMARTER one (Simple Multi Attribute Rating Technique Exploiting Ranks). Note that, as said many times before, this is only one of many different, but possibly efficient, decision processes.

This particular process can be considered an evolution of what discussed at the end of the previous chapter, and it is composed by the following eight steps:

1) Identify the decision maker(s);
2) Identify the alternative courses of action;
3) Identify the attributes of the decision;
4) Evaluate the performance of each alternative on each attribute;
5) Assign a weight to each attribute;
6) Compute a weighted average score for each alternative;
7) Make a provisional decision;
8) Perform a sensitivity analysis.

1 Identify the decision maker(s) – Intuitively, in the first step of the SMARTER process the decision maker is identified.

2 Identify the alternative courses of action – In the second step, all the possible courses of action are outlined (in this case, this step is implemented with the help of the solution map).

3 Identify the attributes of the decision – Similarly to others Multi-attribute models, the third step consists in the definition of a set of attributes, or criteria, that are influenced by the decision.

4 Evaluate the performance of each alternative on each attribute – In this step, some sort of grade, mark, or value is given to each combination alternative – attribute.

5 Assign a weight to each attribute – In the fifth step, a weight is assigned to each attribute, in this manner it is possible to represents the importance of the attribute in the given context. Note that the logic used to the assignation of the weight is the ROC (Rank Order Centroid) that assign a higher weight to the most important attribute, and the sum of the weight of all attributes is equal to one.

6 Compute a weighted average score for each alternative – In the sixth step, the average of the attribute score for each alternative are computed. This is done firstly by multiplying the relative attribute value of the chosen alternative for its multiplier, in this manner the single attribute score is calculated. Then, to obtain the total average score, it is necessary to sum all the attribute scores previously obtained for the given alternative.

7 Make a provisional decision – In this step, a provisional ranking for all the alternatives are defined. This ranking has the only purpose to order the alternatives relatively to their weighted average score.

8 Perform a sensitivity analysis – The last step of the SMARTER approach consists in a sensitivity analysis for the solution given. This type of analysis has the purpose to evaluate how much the obtained results are sensible to any type of variations. This is necessary because the technique used in the fourth and fifth steps is usually subjective and consequently subject to errors.

Once the SMARTER analysis is done it is possible to evaluate with the decision maker(s) the best solution to the given problem.

The following figure is the conclusive solution map and SMARTER table for the example of figure 22.

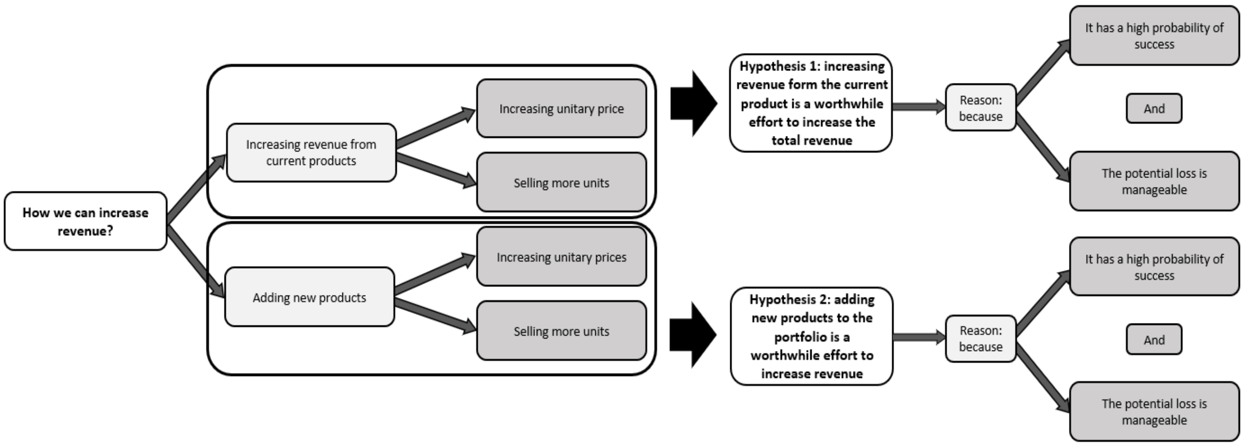

Figure 24 Complete solution map for the example of figure 22

	Low cost	Speed of success	Individual likelihood of success	Weighted score	Ranking
Weight	0.111	0.278	0.611		
H_1: Increasing revenue for current product	100	52	73	70.159	1
H_2: Adding new products	68	97	31	53.455	2
Note: The score for each couple attribute - alternative vary between 0 and 100. The sum of the weight is 1.					

Table 19 SMARTER table for the example of figure 22

As it is possible to notice, in this scenario both the hypotheses have passed the evidence test and are evaluated in the SMARTER table.

3.1.5. Solution implementation and monitoring

The last step for the decision-making process consists in the implementation and monitor of the chosen alternative. In this sub-paragraph will be briefly discussed a series of things, inherent with the decision process discussed above, to bear in mind in the implementation of an alternative and in the monitoring of it. Note that a deeper discussion on this argument will be made in the following paragraph.

The first thing to remember is to update all the maps every time a new information appears, this has to be done as the constant presence of uncertainty and risk can influence all the evaluation done in the decision process.

The second thing to remember is to document everything that appear useful. In this manner it is possible improve the entire process, moreover, differently form the human memory, a document well stored can keep more details and information for a long period of time.

The last, but most important, thing to do, is to identify a series of metrics to take under control during the monitoring process. In this manner it is possible to evaluate the variance between what planned and reality, and consequently, where possible, apply some sort of correction to keep the gap as small as possible.

Obviously, in a scenario where the decision made have the purpose to start a project (Example figure 19 - 22), it is necessary to organize correctly the project with the use of project plans and work plans. As a matter of facts, a bad organized project can increase the variance between what planned and reality, and in the worst scenario can also kill it, leading to a failure. It is also equally important to manage correctly the project. In this case, a constant communication and coherent organization of the project team, connected with an efficient communication with the client, can reduce the variance and lead to an optimal result.

3.2. Post - decision analysis

As seen in the previous paragraph, the process of making decision do not end after the implementation. As a matter of facts, it is necessary to evaluate, for a predefined period, all the positive, but also negative, implications derived by the decision. In the course of this particular period it is also important to be prepared to the failure, a good decision maker make almost always a good decision, but this does not mean that every decision that it made leads to a success.

The following two sub-paragraphs are dedicated to the discussion about the monitoring of the post-decision situation, with a particular attention to the scenario in which a possible good decision become a concrete failure.

3.2.1. Post - decision evaluation

The following paragraph is adapted from: Lucia Antoniette D., Lepsinger Richard, The Art and Science of 360° Feedback.

The logical direction of this chapter is to analyze and discuss the decision-making process form a "human view point". Consequently, the focus of the following discussion will be centered in the evaluation of the impact of a decision on the people affected by it. Obviously, in the following chapter will be discussed a series of measurements dedicated to the post-decision evaluation from a more general point of view (to give an idea, one of them is the cost view point).

This particular sub-paragraph work around the concept of feedback, or more precisely a 360° feedback. This type of feedback can be defined as a process that "involves collecting perceptions about a person's behavior and the impact of that behavior from the person's boss or bosses, direct reports, colleagues, fellow members of project teams, internal and external customers and suppliers" [73]. Shifting the attention on a general decision-maker, from the previous quote it is possible to notice that this method can be very useful in the evaluation of how a decision, and consequently the decision-maker itself, is perceived from the people that composes its environment. After all, the reputation of a person is made by the perception of all the people that surround that person, and suddenly, in a social context, it is easier to disrupt that reputation rather than improving it.

[73] Lucia Antoniette D., Lepsinger Richard, The Art and Science of 360° Feedback, Jossey-Bass Pfeiffer, 1997, pg. 6.

Obviously, it is necessary to remind that this approach is necessary only under specific conditions, an evaluation of the trade-off between the social impact of the decision made and cost/time value of the feedback instruments used is mandatory.

In this particular vision of the firm there are two major instrument categories able to give a sensible and concrete feedback:

- Questionnaires;
- Interviews.

Questionnaires

The first evaluating instrument proposed is the questionnaire. "Questionnaires gather feedback in the form of numerical or quantitative ratings on specific behaviors or personal characteristics. For each question, the rater is given a choice of responses, which usually take the form of a range of options that ask raters how frequently (for example, always to never) or how well (for example, very well to very poorly) the behavior is used or to what extent (for example, a great extent or not at all) the manager in questions displays a certain characteristic." [74]

Note that the data gathered from a questionnaire is predominately quantitative (more numerical and rigid) rather than qualitative (more flexible and richer in informational power).

Differently from the interviews, the use of a questionnaire can bring a series of major advantages. First of all, it requires less time and money to be protracted and completed, improving the previously discussed trade-off.

Another advantage is the size of the data obtained, as a matter of facts, with a questionnaire it results easy to obtain solid evidences about the questions written on it.

Finally, the last advantage consists in the possibility to gather anonymous data, with a reduction of possible omissions and incorrect, misleading information.

[74] Lucia Antoniette D., Lepsinger Richard, The Art and Science of 360° Feedback, Jossey-Bass Pfeiffer, 1997, pg. 47.

Interviews

The way in which interviews gather information is very different from the questionnaire as it is intuitable from the following quote. “Although the interviewer generally uses a structured format of prepared questions, many of them are indeed open-ended; the interviewer will thus hear broad opinions and perceptions and can then probe for concrete examples and clarify answers that could be interpreted more than one way. At the same time, more specific questions are used to elicit information about particular areas of behavior” [75]

It is possible to outline two different categories of interviews:

- One-to-one interview;
- Group interview.

One-to-one interview – one-to-one interviews, as it is intuitable from the name, are a particular type of interviews in which there are only two participants for each session, an interviewer and an interviewee. This structure can results more “friendly” towards the interviewee as it is less influenced by the group dynamics typical of the group workshop, and moreover reduce the possibility of interference in the data gathered, obviously all this at a higher monetary cost.

Group interviews – Differently from the previous definition, group workshops are a particular type of interview in which a group of usually twenty interviewees work and discuss together in presence of an interviewer. This not only reduces the total monetary expenses but also can results useful to build a collective perception towards the changes made by the decision-maker.

Note that it is also possible to do digitally driven interviews, that can be represented as an intermediate between an interview and a questionnaire, as the question for the interview are recorded. The main problem of this method is that sometimes require a higher commitment for the interviewee and can leads to a lower data quality.

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[75] Lucia Antoniette D., Lepsinger Richard, The Art and Science of 360° Feedback, Jossey-Bass Pfeiffer, 1997, pg. 48.

In conclusion, it is useful to discuss about some advantages connected with the use of interviews. One of the main advantages related with the interviews is the possibility, for an expert interviewer, to be able to read between the lines and consequently catch little but sometimes very important details.

A second advantage is to be able to gather more customized data as the answer for each question is not given, and moreover the questions can be forged to be adapted perfectly to the given situation.

The last remarkable advantage is that it furnishes an opportunity to learn the personal characteristic of each interviewee, a double side effect that can be useful in every situation outside the feedback needed for the post-decision evaluation.

It is important to outline that the objective of the feedback is to made the decision-maker aware of the environmental conditions after the decision and, most importantly, to intervene with the purpose to correct the trajectory and reduce the distances between what forecasted and the actual reality.

3.2.2. Acknowledging and learning from failure

Differently from the previous one, this sub-paragraph is focused on the psychological and behavioral elements that can transform a decision in failure, and more importantly, in how to learn from it.

Talking about elements that can transform a decision in a failure, it is possible to outline three different categories of human errors that can appear during, and after, the process of decision making:

- Skill-based errors;
- Knowledge-based errors;
- Rule-based errors.

Skill-based errors

The fist typology of errors are the skill-based ones, they are concerned with the detection of errors strictly connected with the over attention and inattention of the decision maker in the entire process of decision-making. The following table represents a possible list for this type of errors.

INATTENTION	
Omission following interruption	Phone rings part way through an action
Reduced intentionality	Opening the refrigerator and failing to remember why
Perceptual confusions	Pouring tea into the sugar bowl
Interference errors	Trying to do things and partially doing each, like making tea and feeding the cat and ending up putting cat food in tea pot
Double-capture slips	Writing one's old address on a letter
OVER ATTENTION	
Omissions	Failing to boil the water when making tea
Repetitions	Pouring water into an already full teapot
Reversals	Taking off shoes intending to put on slippers only to put shoes back on

Table 20 Skill-based errors [76]

Knowledge-based errors

The second, most important and relevant, typology of errors is the knowledge-based one, differently from the previous category, this category contains a series of errors connected with the use or misuse of the knowledge possessed by the decision-maker.

[76] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 43.

The following table outline eleven different types of knowledge-based errors. Note that some of them has been already discussed at the end of chapter one.

Selectivity	Attending to the 'wrong information'
Workspace limitations	Selecting an inappropriate framework or model for understanding the situation at hand
Out of sight out of mind	Ignoring data which is not readily available and giving undue weight to that which is readily discernible
Confirmation bias	Having made a preliminary judgement on a small amount of information, being unwilling to move from it as more information comes to light
Over-confidence	Particularly in one's own knowledge
Biased reviewing	Less than thorough checking back over the process of problem solving
Illusory correlation	Misjudging a cause effect relationship
Halo effects	Faced with different orderings individuals will be inclined to reduce these to a single order
Problems with causality	General oversimplification of relationships
Problem with complexity	A major grouping which includes difficulties associated with handing multi-causality and lags in feedback
Problem of diagnosis in everyday situations	Difficulties arising from trying to assess symptoms and simultaneously develop a hypothesis

Table 21 Knowledge-based errors [77]

Rule-based errors

The last category of errors that is possible to encounter is the rule-based one. This category represents errors connected with the incorrect use of rules. It is possible to distinguish among two different variants of this type of errors.

- Misapplication of good rules;

[77] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 44.

- Application of bad rules.

Misapplication of good rules – for misapplication of good rules is intended a situation in which a routine or pattern created with a valid regulatory purpose is applied in an incorrect way.

Application of bad rules – Intuitively, for application of bad rules is intended a situation in which the decision-maker intentionally apply bad routines or patterns.

The following discussion is adapted from: Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach.

Once defined the basic categories of errors that leads to failure it is now possible to introduce a method that aims to the analysis and evaluation of that failure. This particular method is called 'Systems failure method'.

"In the case of the Systems Failure Method the final goal is a systemic representation of a failure and its context which could in turn lead to some action. The abstraction is achieved by considering a situation and using a variety of diagrammatic techniques to depict it in a way which improves the initial understanding and enables conceptualization of the system or systems that can be said to lie at the core of the failure [...] So at his hearts the Systems Failure Methods has two key features: conceptualization and modelling of the failure as a system(s); and comparison of that system(s)." [78]

After the needed definition it is now possible continue with the discussion. It is so possible to outline seven different steps that composes this peculiar method:

- Pre-analysis;
- Identification of significant failures;
- System selection;
- System modeling;
- Comparison;

[78] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 64.

- Further analysis;
- Synthesis.

The following figure is a graphical representation of the Systems Failure Method.

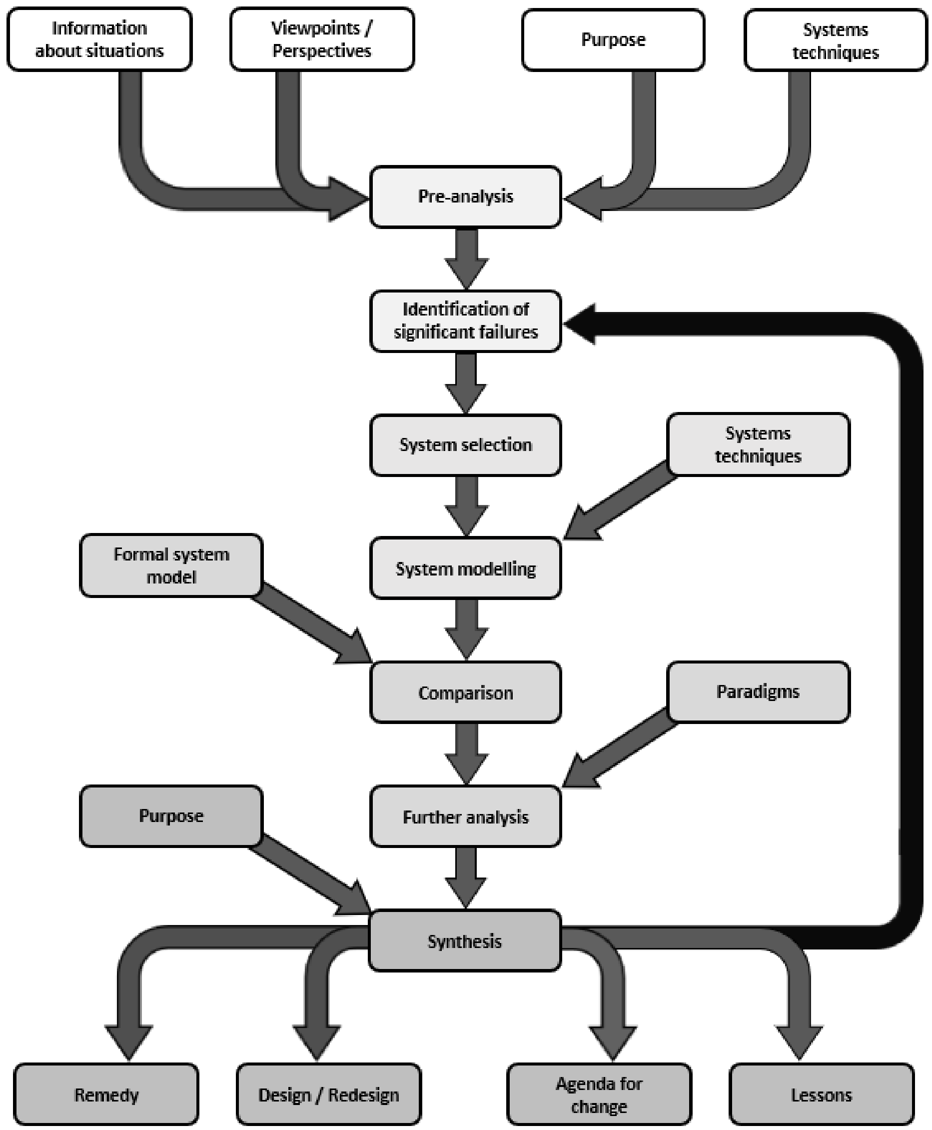

Figure 25 The stages of the systems failure method[79]

[79] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 92.

1 Pre-analysis

The first step of the System failures method is the pre-analysis. In this step different viewpoints and perspectives, and all the known information about the situation and its history are bring together with the use of different representation techniques.

There are four common techniques able to do this job:

- Spray diagrams;
- Rich pictures;
- Relationship diagrams;
- Multiple-cause diagrams.

Spray diagrams – A spray diagram is generally used in the early stages to represent the correlations between the events that caused the failure. Usually it starts from a generic relationship and then it expands like a cobweb as the everts are further subdivided.

Rich pictures – usually associated with the Soft System Methodology (SSM) this technique has the purpose to define the failure with the use of a cartoon-like representation for the elements involved. As an example, in an airplane crash will be represented graphically an airplane, the landing strep and also all the other elements involved in the failure, like an ambulance that came too late.

Relationship diagrams – "Relationship diagrams provide snapshot of situations. Lines are drawn to connect components which are significantly related in some way. Although the nature of the relationships is not specified, the lengths of line can be used to imply different degree of closeness" [80]

[80] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 97.

Multiple-cause diagrams – The last technique is the multiple-cause diagram. The purpose of this technique is to outline why a certain event, or class of events, happened.

2 Identification of significant failures

Intuitively, in this step the focus is shifted on the individuation of all the failure or failures that have emerged in that precise scenario under consideration.

3 System selection

Once defined all the possible failures, the next step is to outline all the systems, or elements, relevant to the born of that series of failures. As an example, in an airplane crash it is possible to outline the firefighting system, the emergency rescue system, the aircraft repair and maintenance system, and so on.

4 System modeling

The fourth step consists in the action of modelling all the systems outlined in the previous step.

It is possible to outline the following three main modelling tools:

- Input-output diagrams;
- Systems maps;
- Influence diagrams.

Input-output diagrams – the input-output diagram for a system has the purpose to represents, with directed arrows, all the elements that pass through a system as an input and an output, and with a box the system itself.

Systems maps – Systems maps are used to represents a snapshot of the situation, showing the components of every system and its environment in a specific point in time.

Influence diagrams – The last modelling tool is the influence diagram. Starting from the systems maps, the purpose of this instrument is to outline all the relationships involved between all the systems and their elements.

5 Comparison

"The process that lies at the heart of the Systems Failure Method is comparison. Understanding is achieved by comparing systemic representations of the failure situation with models of who a situation should be structured and managed if it is to be capable of operating without failure" [81]

In the comparison procedure it is usual to find one or more of the following typical difference points:

- Inadequate design of the subsystems;
- Deficiencies in the apparent organizational structure of the system;
- No clear statements of purpose supplied in a comprehensible form to the system from the wider system;
- Differences in the performance of one or more sub-systems;
- Lack of an effective communications between sub-systems;
- Not enough consideration of the environment that surround the systems;
- Imbalance between the resources used in the systems.

6 Further analysis

The following step after the comparison is to do further analysis necessaries to understand the role of three different elements in the main system model:

- Control;
- Communication;
- Human aspects.

[81] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 109.

Control – For control is intended an action that a system or sub-system applies to itself to maintain the desired state.

Communication – Intuitively, for communication are intended all the various communication processes that happened inside the main system model, between main system and the environment, between systems, and between system and sub-systems.

Human aspects – The last element has the purpose to evaluate role of the human component in the failure. Note that, to improve the analysis, the human component can be further divided in the following three sub sections:

- Human factor at organizational level;
- Human factor at group level;
- Human factor at the level of individual.

Lastly, to give an idea of the importance of the human aspect, the following chart represents the impact of the human presence in a failure scenario.

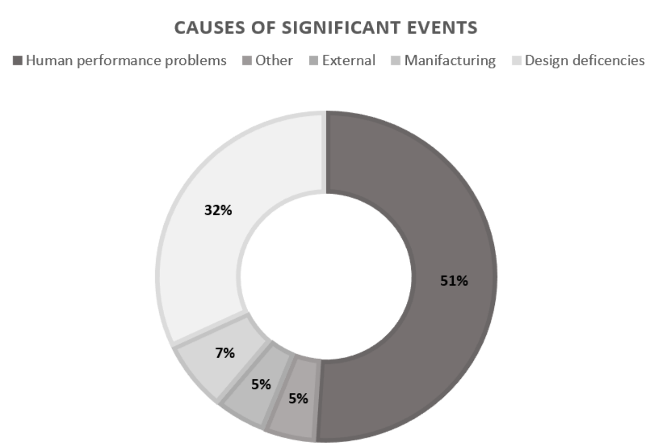

Figure 26 percentage of causes of failure (1991) [82]

[82] Fortune Joyce, Peters Geoff, Learning from Failure: the systems approach, Wiley,1995, pg. 135.

7 Synthesis

The final step of the Systems Failure Method is the Synthesis. In this last step the entire Systems Failure Method is synthetized and checked. If the obtained solution can result in other failure, the entire process is iterated (as shown in figure 25), if not, a series of important results (such as possible remedy, lessons, agenda, design) can be successively used to fix the failure object of analysis.

3.3. Teams dynamics and decision making

The following paragraph has, as a main goal, the discussion about the complex dynamics that happen inside every teams. Starting from the Basilar structure, proceeding towards the supposed and real allocation of influential power and decision power, ending with a reflection towards the failure element inside teams.

3.3.1. Teams development structure

"Teams develop though a series of stages that reflect changes in their internal group processes and the demands of their tasks. This perspective of team stages produces one of the most important insights about teams: They often are not productive at the beginning of projects" [83] As it is intuitable from the previous quote, the underlying structure of a team is very complicated and can dictate the course of the project. For this reason, a basilar comprehension about this type of groups formation is fundamental and needed.

The process of team developing is composed by the following five unique steps:

- Forming;
- Storming;

[83] Levi Daniel, Group Dynamics for Teams, Sage Publications, Inc., 2017, pg. 43.

- Norming;
- Performing;
- Adjourning.

The following figure contains a graphical representation of this linear process.

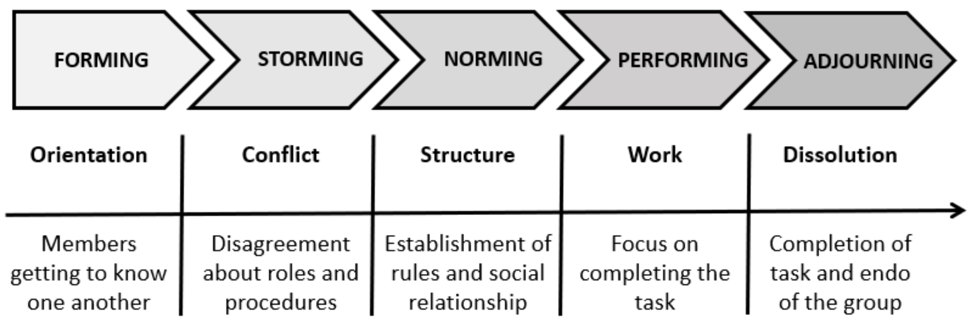

Figure 27 Stages of group development [84]

Forming

The first step of the group development process is forming. In this step team members are getting acquainted between each other's and with the task. In this starting stage, the level of uncertainty on the expectations for the groups are high.

Storming

The second step of this process is the Storming. As the time passes the roles and personalities of the group members became clearer, this can start a series of conflicts between them. The purpose of this step is to permit the resolution of possible disagreement, uncertainties and conflicts that can mine the final performance of the team.

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[84] Levi Daniel, Group Dynamics for Teams, Sage Publications, Inc., 2017, pg. 45.

Norming

In the third step, after the resolution of previous dispute, conflicts, and other disagreement the team start to developing the structure able to make the transition toward a mature team devoted to the performance.

In this step the following two main elements play a big role:

- Norms;
- Roles.

Norms – Team norms can be defined as a set of unwritten rules inside the team. These norms have the purpose to regulate the behavior of the team members in concordance with the expectations of the others components.

> **Roles** – "we all wear many hats in life. We may be – at the same time – friends, neighbors, students, siblings, lovers, employees, and much more. Each of these hat carries with it a set of expectations for its wearer. […] These various hats are called roles."[85]

Performing

In this step the team is finally mature and able to move towards the performance side with the purpose of completing the team mission and achieving every goal set.

Adjourning

In the final step, the team dissolves. This can happen for two reasons, the first one is that the team has accomplished its purpose and its goals. The second reason is a breaking up due to unsolvable discrepancies inside the team members or due to external forces which considers inconvenient the continuation of the project.

[85] Aldag Ramon J., Kuzuhara Loren W., Creating High Performance Teams: applied strategies and tools for managers and team members, Routledge, 2015, pg. 55.

3.3.2. Power types and styles

The power of a person in a team can be considered as the key able to dictate the course of the future decisions. It can be defined as “the capacity or ability to change the beliefs, attitudes, or behaviors of others” [86].

It is important to remark that power do not directly imply leadership, as every team member have its unique bases of power, the difference here consists in the way that it is used.

Generally, it is possible to outline two different types of power:

- Soft power;
- Harish power.

Soft power

The soft power can be considered as the power derived by the personal ability of the team member, this power can be further divided in three different sources:

- Expert;
- Referent;
- Information.

Expert – Intuitively, this type of power is originated by the credibility or the perceived expertise of the subject in a specific area or sector. Very effective in a situation where that area is directly or indirectly connected with the goal, but not so much in the other scenarios.

Referent – The referent power is based on the admiration or liking from the others team members to the person taken in to consideration. Generally effective in every area but less efficient that the expert power.

[86] Levi Daniel, Group Dynamics for Teams, Sage Publications, Inc., 2017, pg. 156.

Information – Differently form the others two sources, the information power is based on the effective knowledge of a person in a specific topic.

Harsh power

The harsh power can be considered as the positional power acquired form a person during its career or form other sources. Similarly to the previous one, this type of power can be further divided in three different sources:

- Legitimate;
- Reward;
- Coercive.

Legitimate – The legitimate power is originated form the recognition and acceptance of the subject authority. Note that this type of power differs in strength on the basis of the cultural context that surround the environment.

Reward – The reward power is connected with the ability to give some sort of rewards to another person if it pursues a specific behavior.

Coercive – Opposite of the reward power, the coercive power is connected with the ability to threat or punish another person if it not pursues a specific behavior.

It is easy to notice that, thanks to its characteristics, the soft power results more effective in almost every situation. Suddenly, the same cannot be said for the harsh power, as it is strictly correlated with factor of culture and perception of power from the surrounding people. Note also that, form a decision-making perspective, the soft power leads to more valid and effective decisions, and consequently it leads to a reduction of failure.

Once defined the sources of power, it is possible to shift the discussion on “How” this power can be effectively impress to other people.

It is so possible to outline three different power styles:

- Passive;
- Aggressive;
- Assertive.

Passive

The passive power style can be considered as polite and deferential. This style is connected with a person that has the tendency to avoid problems and conflicts by not taking position with the use of evasiveness. Usually, but not always, can be associated to an insecure and shy person.

This particular style is very useful in a high emotional conflict, and also in scenarios where a passive response is expected, such as in a subordinate scenario.

Aggressive

The Aggressive style can be considered as the opposite of the previous one. Actually, this style shares with the passive style some basic elements. This type of style can be considered as forceful and negative, where for negative is intended the emotional tone generally used to enforce power. Usually the drivers behind the use of this style are anger, insecurity and lack of trust for the person. This style can results very useful in emergency and critical situations, in which aggressiveness can restore order.

Assertive

The last style discussed in this sub-paragraph is the assertive one. "The assertive style uses clear and confident communication. No emotions are added to messages. Assertiveness is communicating openly with concern for both others and oneself. It is taking responsibility for one's own communication."[87] This type of style can be considered as generally efficient and successful, with higher efficiency where the status between team members are equal, as it can improve communication and problem-solving abilities of the entire team.

[87] Levi Daniel, Group Dynamics for Teams, Sage Publications, Inc., 2017, pg. 170.

3.3.3. Decision-making

The first step towards the understanding of the dynamics that shapes every group decision-making scenario is the discussion about how the decision authority can be distributed inside a team.

The following figure represents the decision-making path that leads to eight different decision options.

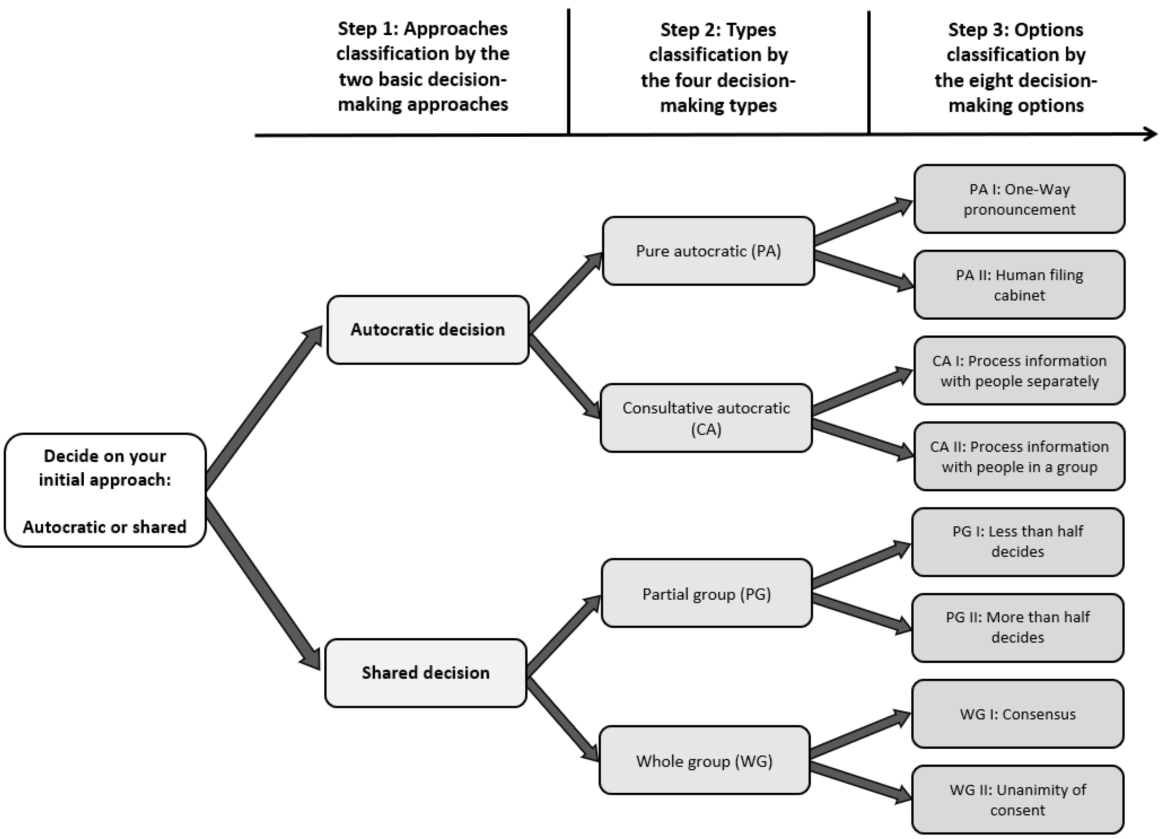

Figure 28 Classification of decision-making options [88]

[88] Kayser Thomas A., Building Team Power: how to unleash the collaborative genius of team for increased engagement, productivity, and results, McGraw-Hill, 2011, pg. 70.

Intuitively from the previous figure, it is possible to separate the two main decision approaches as follows:

- Autocratic decision approach;
- Shared decision approach.

Autocratic approach

In few words, an autocratic decision scenario can be described as a situation where the authority for the final decision remains in the hands of a single person.

The autocratic decision approach contains the four following options:

- One-way pronouncement;
- Human filling cabinet;
- Process information with people separately;
- Process information with people in a group.

One-way pronouncement – Intuitively, the concept behind the one-way pronouncement is simply that one person makes, and successively, shares a decision without asking for information nor consultation. Note that this and the next variants of autocratic decision-making are very useful in situations of emergency, where decision making is centralized and high coordination is mandatory.

Human filling cabinet – In this variant of the pure autocratic type the decision maker is surrounded by a group of people from which it obtains information, in this situation there neither problem nor the need for information is shared.

Process information with people separately – The idea behind this consultative autocratic type of option is that the decision maker shares the problem one to one with the surrounding group of people, defining for each person only the relevant background issues on which the decision maker wants an advice.

Process information with people in a group – In the last type of autocratic option the decision maker shares all the problem and needs with the entire group of people, but retain the final decision-making power.

Shared approach

A shared decision scenario can be described as a situation where the authority for the final decision is shared between more than one person.

The shared decision approach contains the four following options:

- Less than half decides;
- More than half decides;
- Consensus;
- Unanimity of consent.

Less than half decides – "PG I can be very constructive decision-making approach when it becomes apparent, either before or during the discussion, that a group of individuals—comprising less than a half the total group—possesses knowledge, skills, and expertise to make a quality decision that the entire group can support. Realizing this the majority defers final decision-making authority to the minority group"[89]

More than half decides – This approach can be considered very similar to the previous one, but, in this case, the decision power is distributed among a bigger group that contains more than a half of the total group.

Consensus – In the consensus option, every person that belongs to the group have the power vote for the decision. In this scenario, more than a half of all the people must agree with a given course of action.

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[89] Kayser Thomas A., Building Team Power: how to unleash the collaborative genius of team for increased engagement, productivity, and results, McGraw-Hill, 2011, pg. 74.

Unanimity of consent – The last decision-making option is the unanimity of consensus. Intuitively, the logic behind this option is that a course of action is chosen if, and only if, all the people that belong to that specific group agree with that decision. Note that this option is very time consuming as reaching the unanimity on a decision is difficult, for this reason this option should be used only in a scenario where the decision is critical and there are little time constraints.

Before ending this sub-paragraph can results useful give a brief mention to the key forces impacting the choice of decision option.

The following figure is a graphical representation of the relationship between the five key decision elements and the decision options.

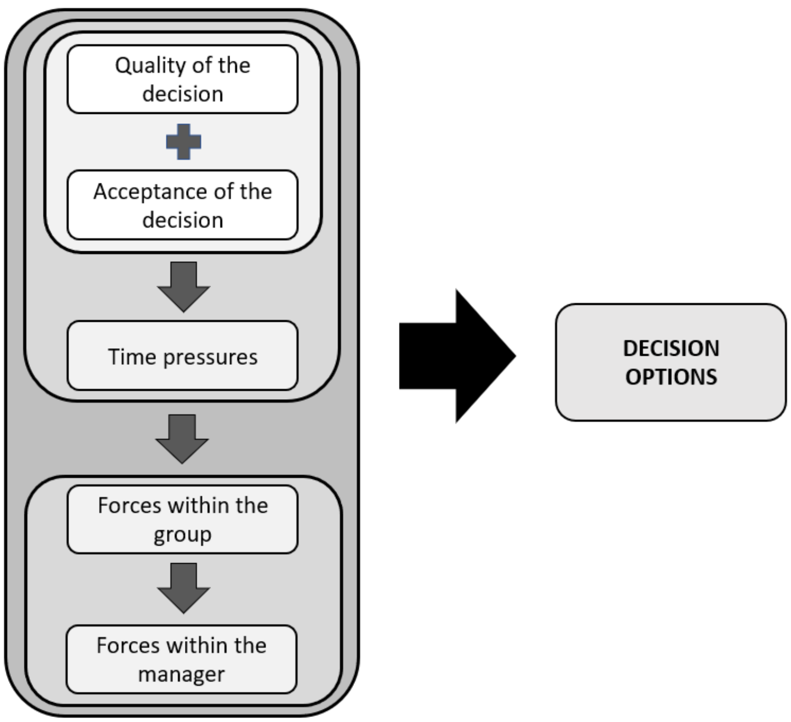

Figure 29 Key elements impacting the choice of a decision option [90]

[90] Kayser Thomas A., Building Team Power: how to unleash the collaborative genius of team for increased engagement, productivity, and results, McGraw-Hill, 2011, pg. 74.

Quality of the decision – For quality of the decision is intended the objective consideration that indicate one specific solution is better than another one.

Acceptance of the decision – The acceptance of the decision is referred to the commitment and support of the decision form the executor(s) of the decision.

Time pressures – Intuitively, this element represent the time frame in which the last decision must be taken.

Forces within the group – For forces within the group are intended all the specific and generic characteristics of the team members (knowledge, experience, etc.) that can influence the decision of the manager.

Forces within the manager – Lastly, the final key element are all the forces within the manager. This particular element represents all the specific and generic characteristics of the manager itself (knowledge, personal style, etc.).

In conclusion, in the evaluation of the best decision structure in a team, a pondered analysis of the trade-off between these five elements is mandatory. It is worth to notice that a misinterpretation of these elements, in the choice of the best decision option, can heavily influence the outcome and, even worse, undermine the entire team.

3.3.4. Problems and conflicts

"properly defining the problem is the crucial first step in the problem-solving process. Failure to do so can cause teams to solve the wrong problem."[91] Every type of problem, team

[91] Aldag Ramon J., Kuzuhara Loren W., Creating High Performance Teams: applied strategies and tools for managers and team members, Routledge, 2015, pg. 211.

problems included, must be resolved as fast as possible or the only outcome will be the split up of the team.

Before entering the topic of team conflict, it is necessary to start from the basis, or with the discussion about self-oriented roles and groupthink effect. These two elements can be considered as a huge undermining problem in a team, also without the presence of any conflicts inside or outside the team boundaries.

Self-oriented roles

The main problem of self-oriented roles in a team is the impact of the behavior of these subjects on the remaining team members.

The following list outline the four major self-oriented roles:

- Freeloaders;
- Complainers;
- Bullies;
- Martyrs.

Note that these particular roles do not necessary leads to conflicts, but for sure they are able to reduce the quality of the final decision.

Freeloaders – A freeloader is a particular type of team member that simply do not carry a fair share of the total team workload. Intuitively, this can heavily reduce the performance and create possible conflicts with the others team members, damaging the team.

Complainers – "These team members constantly complain about the team's scheduling, activities, progress, or other matters. They see the project as a waste of time, fell they aren't being treated well, or simply hate work in teams"[92] In this case, the main source of problems come from

[92] Aldag Ramon J., Kuzuhara Loren W., Creating High Performance Teams: applied strategies and tools for managers and team members, Routledge, 2015, pg. 212.

the negativity of the complainer that is able to damage the team morale, resulting in a damage from the productivity.

Bullies – Bullies or dominators are people that actively force their opinion over the others, seemingly with the purpose to demonstrate that they are more knowledgeable and prepared. In this scenario, the side effect of this approach is a reduction of will and a non-healthy sense of oppression for the others team members.

Martyrs – This specific type of people has the insane tendency to feel that they are the only ones to do something in the team, carrying the entire team, and moreover want that the other team members feel guilty for this reason. This obviously can lead only to contrast with the other people for their claims and attitudes.

Groupthink

The groupthink phenomenon can be defined as "an excessive form of concurrence-seeking among members of high prestige, tightly knit policy-making groups. It is excessive to the extent that the group members have come to value the group (and their being part of it) higher than anything else."[93] As it is possible to notice from the previous quote, groupthink can be very tedious in a team as it is able to reduce exponentially the profitability of successful outcomes.

The following list identifies a series of groupthink symptoms:

- Illusion of invulnerability;
- Belief in the inherent morality of the group;
- Collective rationalization;
- Stereotypes of outsiders;
- Self-censorship;
- Illusion of unanimity;
- Direct pressure on dissenters;

[93] Hart Paul T., Irving L. Janis' Victims of Groupthink, Political Psychology, Vol. 12, No. 2, 1991, pg. 247.

- Self-appointed mindguards.

Illusion of invulnerability – The symptom of illusion of invulnerability leads the team to have an excessive optimism in the alternatives and consequently encourages risky choices.

Belief in the inherent morality of the group – This symptom leads the team to ignore the ethical and moral consequences of their decision.

Collective rationalization – Members of the group have the tendency to discount warnings and do not reevaluate assumptions.

Stereotypes of outsiders – Generally speaking, members of the team have the tendency to see the outsiders weak and incompetent.

Self-censorship – All the variations form the perceived idea of the group, such as doubts and deviations, are blocked form the members itself.

Illusion of unanimity – Intuitively, this symptom can be translated as a false sense of unanimity in the majority opinions and decisions.

Direct pressure on dissenters – Group members that have doubts and deviations from the perceived group avoid to express it as a consequence of the psychological pressure of others members.

Self-appointed mindguards – Minguards are group members that selectively transfer the information to the leader, discarding contradictive and problematic information.

The results of these eight symptoms in the group decision process is translated in the following series of defects:

- Incomplete surveys of alternatives;
- Failure to examine a preferred choice;
- Failure to reexamine rejected alternatives;
- Poor information search;
- Selective bias in processing information;
- Failure to develop contingency plans.

Incomplete surveys of alternatives – Members of the group evaluate only a limited series of alternatives, failing to consider all the possibilities.

Failure to examine a preferred choice – To avoid doubts and deviations the preferred choice is not correctly examined, hiding possible deficiencies.

Failure to reexamine rejected alternatives – unsatisfactory alternatives are no more reexamined leading to the possibility of excluding a better solution.

Poor information search – As a consequence of bias in the team members, the process of collecting information is also biased, leading to collecting impartial data.

Selective bias in processing information – Similarly to the confirmation bias, this particular defect leads the team members to process the information selectively, selecting only the information that confirm their preference.

Failure to develop contingency plans – Since members do not expect resistance or problem in the application of the preferred alternative, a backup plan is seen a waste of time.

Once concluded the discussion about self-oriented roles and groupthink effect, it is now possible to shift the attention toward the conflict element. Conflicts are at the basis of every relation between two or more people.

Conflicts can create, but also undermine, relations. “All organization experience conflict. Teams may experience both conflict within teams—intrateam conflict—and conflict between teams—interteam conflict. There are many costs, but also many potential benefits, to conflict. The way in which conflict is handled determines whether it is beneficial or destructive. As such, the challenge is not to eliminate conflict but to ensure that is effectively managed.”[94]

It is possible to define two different types of conflicts:

- Interpersonal conflict;
- Task conflict.

Interpersonal conflict – The interpersonal conflict can be defined as all the conflicts correlated with the relationship side of the members and with the different ideas on the process that should lead to the goal. These types of conflicts interfere with three different dimensions: status, compatibility, and commitment.

Task conflict – Task conflicts are all the conflicts generated by different ideas and opinions correlated with the team’s task. In this scenario it is possible to outline three different dimensions of the conflict: divergent task, convergent task, and logistical coordination.

Once defined the types of conflicts it is necessary to move toward the description of the five common conflict styles. The logic behind the definition of these styles is based on the combination generated by the presence or not of two different elements, assertiveness and cooperativeness.

As said before, it is possible to outline a total of four different styles, one for each combination of assertiveness and cooperativeness, plus one additional style, as a compromise between them.

[94] Aldag Ramon J., Kuzuhara Loren W., Creating High Performance Teams: applied strategies and tools for managers and team members, Routledge, 2015, pg. 218.

- Competing;
- Avoiding;
- Compromising;
- Accommodating;
- Collaborating.

The following figure is a graphical representation of the previously defined conflict styles.

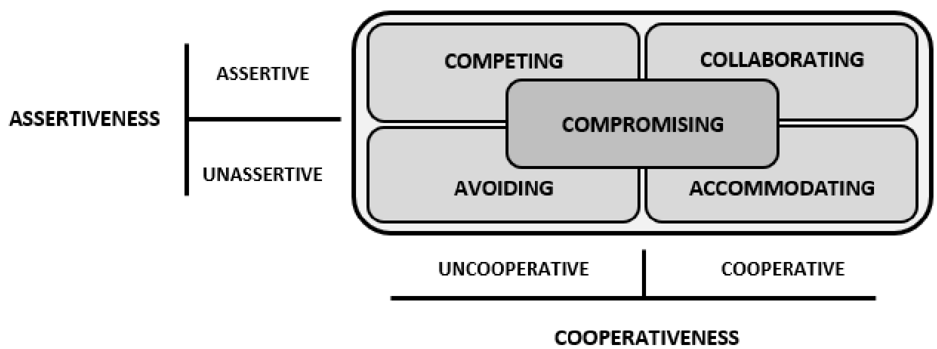

Figure 30 Conflict styles [95]

Competing – The competing (or forcing) style is typical of person that want to satisfy only his/her needs at the expenses of the counterpart/s. The resulting conflict is in a form win-lose as it is impossible to move the person toward an integrative vision.

Avoiding – The avoiding style is nether assertive nor cooperative. The tendency is to avoid the conflict by avoiding to take part in the conflict. This type of style leads to a lose-lose situation, as no one wins the conflict.

[95] Aldag Ramon J., Kuzuhara Loren W., Creating High Performance Teams: applied strategies and tools for managers and team members, Routledge, 2015, pg. 224.

Compromising – The compromising style can be defined as a mid-way between assertiveness and cooperativeness. This style does not fully satisfy both parts but neither does fully unsatisfied them.

Accommodating – With the use of the accommodating style the person is cooperative towards the other part but lack in assertiveness. This style generates a win-lose situation, where the lose side is picked by the accommodating person.

Collaborating – Intuitively, the collaborating style is referred to a situation where both parts collaborate. In this manner a win-win situation is created, this because the interests of both parts are satisfied. Obviously, this type of style is the best one in a conflict situation but require a high presence of trust, open sharing of information, and creativity.

3.4. Subjective assessment and forecasting

"All of us are used to making judgements reading uncertainty, and we make them frequently. Often our statements involve informal evaluations of the uncertainty that surround an event. Statements such as "The weather is likely to be sunny today" […] all involve a personal subjective assessment of uncertainty at a fundamental level. As we have seen, subjective assessments of uncertainty are an important element of decision analysis."[96]

Intuitively, the purpose of this paragraph is to discuss about the presence of subjective assessment in the decision-making process, but, more importantly, about the influence of this element in an environment rich of uncertainty such as in the forecasting activity.

This paragraph can be considered as a middle ground between this and the previous chapter as the first sub-paragraph revive the concept of uncertainty in decisions but from a human perspective, and the second sub-paragraph presents some mathematical models that can help in the forecasting process.

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[96] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 265.

3.4.1. Subjective probability assessment

In every decision situation, the decision maker is subject to the uncertainty element in a variable quantity. Sometimes this uncertainty can be imperceptible and can be ignored, other times can play a small or even big roles in the outcome performance of the decision taken. In the latter scenario, leave to the decision-maker the burden to assess the probability for the likelihood of an event cannot be a valid option, this because the decision-maker do not usually possess all the knowledge needed. In this case the use of experts in probability assessing is the best solution.

The probability assessment in a subjective scenario can be defined in the following seven steps:

- Identification of background elements;
- Experts identification and recruitment;
- Motivating experts;
- Structuring and decomposition;
- Probability-assessment training;
- Probability elicitation and verification;
- Aggregation of expert’s probability distributions.

Identification of background elements

The first step consists in the individuation of all the variables in which the assessment of an expert is necessary. An evaluation of the knowledge needed for each variable is fundamental, as it serve the purpose to outline the knowledge boundaries and target the right pull of experts.

Experts identification and recruitment

In the second step, experts are identified and recruited inside the team. Experts can be founded inside the company, as an example from others departments, or even externally through the use of external organizations.

Motivating experts

The third step has the purpose to motivate the experts for their role, increasing their enthusiasm for the project. "Typically, they are scientists themselves and prefer to rely on the process of science to generate knowledge. Their opinions may not be "correct", and hence they hesitate to express those opinions. The fact remains, though, that a decision must be made with the limited information available" [97]

Structuring and decomposition

In the fourth step, an identification of the experts understanding of casual and statistical relationship among the relevant variables is needed. The purpose of this step is to outline a general model that reflects the experts thinking about the variables.

Probability-assessment training

The fifth step consists in a training of the experts on probability assessment. This is necessary as it permits the expert to dramatically improve the outcome of their probability assessment.

Probability elicitation and verification

In the sixth step the experts make all the required probability assessments, usually under the guidance of an expert of probability elicitation processes. Obviously, all the assessments are checked under a probability and consistency point of view, to reduce distraction errors and to logically connect chain of probability assessments.

Aggregation of Expert's probability distributions

In the seven, and last, step all the expert's probability distributions are aggregated with the purpose of generate a single, complete, distribution for the use of the decision maker. This can be done in two way. The first one consists in the use of a consensus distribution, but it can carry the risk of biases in the expert opinion. The second one instead consists in the use of mathematical

[97] Clemen Robert T., Making Hard Decision: an introduction to decision analysis, Duxbury Press, 1996, pg. 292.

formulas, such as the average, to obtain the final distribution. Obviously, with the drawback of ignoring the relative expertise among the experts.

3.4.2. Forecasting models

"Every manager forecast, since every considered decision he takes will involve making an assessment about the future. Managers and their organizations do survive despite bad forecasting but severe penalties are often paid. […] Forecasting should not be seen as a magic art, but rather as a systematic way of learning from past data and information and of incorporating judgement about the future into the forecast made."[98]

Forecasting models falls into the following three different categories:

- Statistical forecasting models;
- Casual forecasting models;
- Judgmental forecasting models.

Statistical forecasting models

The first forecasting category consists in a series of models that simply use past data to make previsions.

"the fundamental assumption underpinning statistical forecasting models is that future patterns will be extensions of past patterns ant that these patterns are completely encapsulated in a set of past data values."[99]

It is possible to outline the following two common models that belongs to this category:

- Time series analysis;
- Moving averages.

[98] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 252.
[99] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 254.

Time series analysis – Time series analysis is a technique in which a set of data forming a series over time are broken in sub-parts used to make a forecast.

In this type of analysis there is a standard series of patterns:

- Random interactions;
- Irregular changes;
- Seasonal variation;
- Trend;
- Cyclical variation.

Each one of them is graphically represented in the following figure.

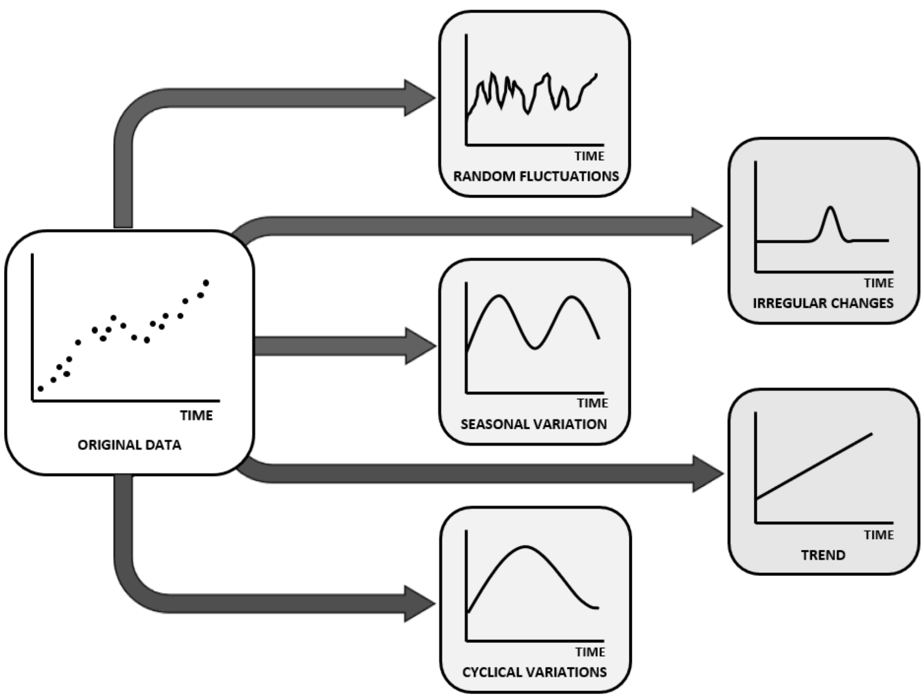

Figure 31 Time series analysis [100]

[100] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 257.

Once defined the basic series of patterns that composes the event that has to be forecasted it is possible to reconstruct the starting series. This can be done by multiplying or adding each series of patterns between them to obtain again the starting series. (SALES = TREND + SEASONAL VARIATION x RANDOM FLUCTUATIONS as an example). Note that the multiplier is used when two patterns are correlated and a variation in one pattern is correlated to another one. As regards the addition, it is used to outline a scenario where two particular patterns are independent.

Once determined the trend it is now possible to forecasts for the future using the previously defined formula.

Moving averages – Intuitively form the name, moving averages consists in making the average of the data for a certain period of time, usually between three and twelve months. The purpose of this instrument is to outline trends from the starting data by smoothing it and by making the average of that values for a certain prearranged period of time.

This particular instrument should be used with criterion as it not always works, especially with particular patterns, and moreover a slight change in the time unit chosen can leads to a totally different trend.

Casual forecasting models

Casual forecasting models can be considered as an evolution of the statistical forecasting models as it also attempts to understand the link between two variables. As a matter of facts, casual models should be able to predict immediately the consequences of variations in the data collected. This cannot happen in a quantitative forecasting model, such as statistical forecasting, as the change can be seen only when enough data of the change are available, penalizing the forecast.

Judgmental forecasting models

The last type of forecasting models is the judgmental one. “When neither suitable data exists nor sufficiently understood quantifiable factors are resent to allow a casual model to be built, then reliance must be placed on judgement alone."[101] In this scenario, as there is no possible pattern that can be used to make a valid forecast based on the previous models, the only solution is to follow the way of the subjective probability assessment discussed in the previous sub-paragraph.

[101] Finlay Pauln N., Mathematical Modelling in Business Decision-Making, Croom Helm Ltd. 1985, pg. 274.

CHAPTER 4

Management control: data gathering and decisions

The last chapter of this thesis shift the focus towards a more managerial and concrete view point of the decision making. More deeply, the shift is made towards a scenario in which the decision-maker has the role of a controller, or a similar role at strict contact with the managerial accounting discipline. Note that the great majority of the following discussion can be applied also to other roles. In this scenario it is possible to outline a yet different, more specific, cycle of problem solving.

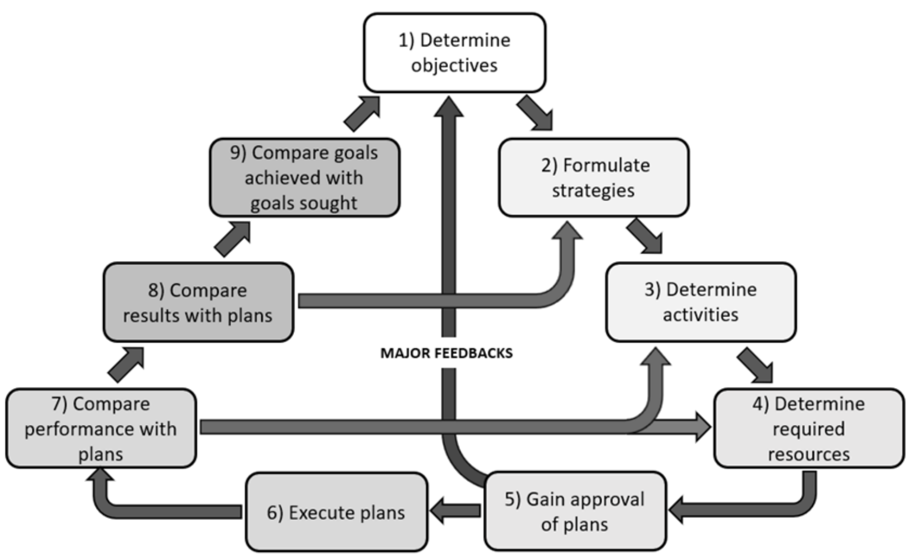

Figure 32 The cycle of control in problem-solving [102]

[102] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 65.

In this scenario the two fundamental elements that dictate the course of action are uncertainty, that can be reduced with the quality of the set of information, and the time unit. These two elements will be discussed in the following paragraphs.

4.1. The importance of data and information quality in decision making

"The quality of information is paramount. […] Systems that have been implemented with poor user interfaces but high - quality content are generally regarded as successful, whereas systems that have failed to correctly migrate data, even with the best user interfaces, are regarded as abject failures. In other words, in both business management and technology implementation, there is a direct causal relationship between the quality of information and successful outcomes." [103]

Before starting with the discussion about the quality of the data or information it is useful to introduce the concept of data and information assets. Intuitively, data and information can be considered assets for an organization when they can be considered as important or even fundamental for its success.

It is important to remark that between data and information there is a distinctive difference, the first one is referred to a generic set of symbols, signs or raw facts. As regards information it can be considered as an evolution of the previous concept, where at the raw data is added a meaning or purpose.

Note that nowadays the great majority of the data and information are stored, or can be transformed, in a digital form, consequently, in the continuation of the discussion, for data and information is usually intended electronic one. But this do not imply that the discussion cannot be applied to their more classical conception.

[103] Hillard Robert, Information-Driven Business: how to manage data and information for maximum advantage, John Wiley and Sons, Inc., 2010, pg. 156.

It is so possible to outline three different structure for data and information assets:

- Structured;
- Semi-structured;
- Unstructured.

Structured data and information

Structured data can be considered as the best form in which data can be, this because this particular form implies that data is stored in different tables connected by relationships, in this manner, a manager can obtain the needed data only knowing a significative keyword. This type of data is easy to access and can be almost immediately consulted and used form the manager.

Semi-structured data and information

Differently from structured data, this type of data is also stored in tables but there is no link between them. A common example is the data generally found in internet through a research.

Unstructured data and information

The last form of data is the unstructured one. In this particular state, data is not readily available at a request as it is not in a structured form of tables and there no relationships or links between them. Some example of this can be emails, saved presentations of a product, hardcopy documents.

Similarly to a product, also data and information have a lifecycle. "Like a product in its early life, information needs to be created, organized, and stored. To make use of information for analysis and decision making, it needs to be distributed to the relevant storage systems and retrieved from these storage systems. Processing may also occur before retrieval. Finally, at the end of the life of the information, it can be archived, if required, or deleted."[104]

[104] Borek Alexander, Parlikad Ajith, Webb Jela, Woodall Philip, Total Information Risk Management: maximizing the value of data and information assets, Elsevier Inc., 2014, pg. 10.

The previously defined data lifecycle can be synthetized in the following figure.

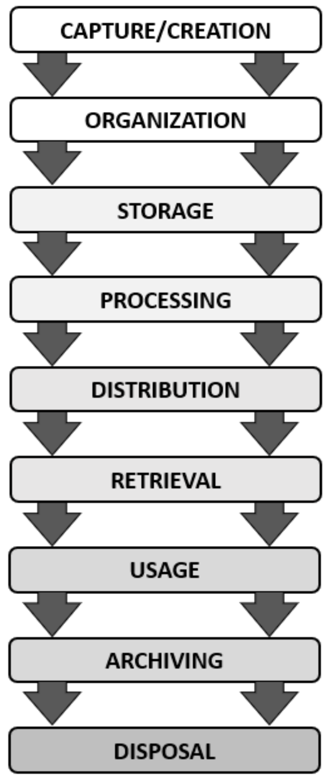

Figure 33 Data and information lifecycle

Once briefly defined the basic elements of data and information in a managerial context it is now possible to shift the discussion towards the quality of the data. Quality of data asset is a particular concept and can be defined as the fitness for use of data and information. It is useful to notice that the level of quality is strictly correlated with the context in which the data or information need to be used.

Intuitively, Information Quality (IQ) rely on a series of different, but fundamental dimensions that can be categorized as follows:

- Intrinsic IQ;
- Contextual IQ;
- Representational IQ;
- Accessibility IQ.

Intrinsic IQ

Intrinsic information quality category aggregates all the dimensions that have, as a purpose, the ability to delineate if an information has quality in its own rights.

This category comprehends the following dimensions: accuracy, precision, reliability, and freedom from bias.

Contextual IQ

The contextual information quality category has the purpose to highlight all the dimensions correlated with the importance of the context in the evaluation of the quality of the information. These dimensions are: importance, relevance, usefulness, informativeness, content, sufficiency, completeness, currency, and timeliness.

Representational IQ

Representational information quality category concentrates all the dimensions related with the way in which the information is presented to the manager. The dimensions represented by this category are: understandability, readability, clarity, format, appearance, conciseness, uniqueness, comparability.

Accessibility IQ

Lastly, the accessibility information quality category represents a series of dimensions inherent with the level of accessibility of the informeation for the manager. These dimensions are: usability, quantitativeness, convenience of access.

It is important to notice that there is not only one model to represent the quality of the information and consequently the model proposed is only one of many available in the current and past literature.

The following figure has the purpose to give a graphical idea of the dimensions that composes the information quality.

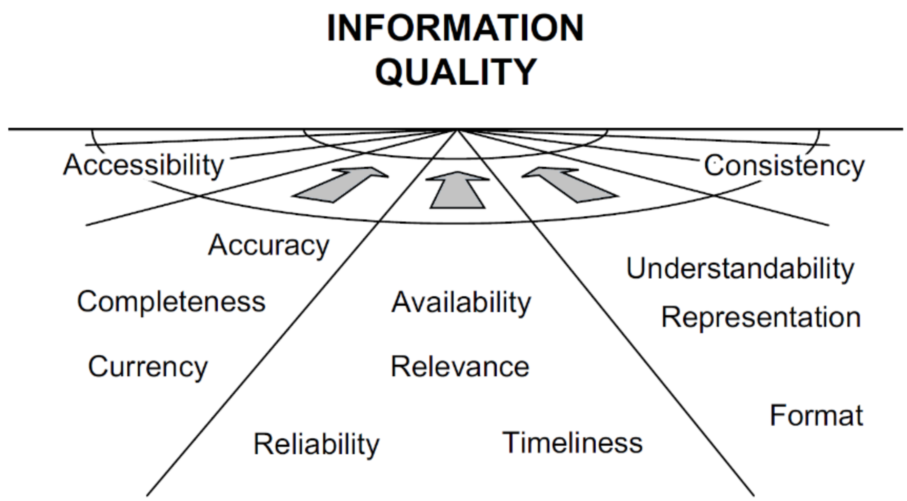

Figure 34 Data and information quality dimension [105]

In conclusion, in the decision-making process the quality of the information at disposal of the decision maker is strictly correlated with the quality of the outcome of his/her decisions.

Intuitively, analyzing the dimensions of information quality, the level of quality in the information that reach the decision maker is strictly correlated with the level of uncertainty and risk associated with that particular decision. A well-structured and high-quality set of information leads almost always too fast and better decisions and, as a consequence, to a lower risk of failure and better results.

[105] Borek Alexander, Parlikad Ajith, Webb Jela, Woodall Philip, Total Information Risk Management: maximizing the value of data and information assets, Elsevier Inc., 2014, pg. 13.

4.2. Feedforward control and decisions

The purpose of this paragraph is to outline the way in which data, information, and decision-making interact with each other in a managerial context. The primary time orientation is the future, here the main goal is to control that future, and the better way to effectively control the future is to make the right decision with the available data and information.

4.2.1. Planning current activities

"Managerial accounting does not exist for its own sake: it exists to enable managers to make better decisions and thereby improve the effectiveness of their organizations" [106]

Before starting the discussion about cost allocation as an instrument for planning, it is necessary to start from the basis and with a briefly discussion about the common denominator between the various cost allocation methods, usually known as the nature of cost.

A cost can be defined as a monetary measurement of a specific amount of resources used for a defined purpose. The fact that is a measurement unit for a quantity of resources is pretty obvious as a consequence of the concept that transmit the word 'cost'. Differently, more important is the concept of motivation behind the use of these resources. For decision-making (as regards the controller figure) the purpose for which cost is encountered is fundamental to define the economic reality of the firm. As it is intuitable from the previous sentence, it is mandatory to outline that cost it is not always equivalent to a cash outflow, it is here that the importance for the concept of cost came to light.

"Different costs for different purposes. It is important to recognize that the term 'cost' only has meaning in a given context and always require an adjective accompanying it to avoid confusion. There are different cost concepts that are appropriate for different purposes, and no single concept is relevant for all situations." [107]

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[106] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 75.

[107] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 78.

The fundamental bricks for the nature of cost are the cost objects. Cost object can be defined as a technical name for the product, project, organizational unit or activity for which costs are measured. Note that the definition for the boundaries of the cost object can be broad (an entire department as a cost object) or narrow (in a scenario where the cost object is a single product variant). Intuitively, this different definition of the boundaries is strictly correlated with the environment and the purpose for which costs need to be measured.

In the history of management different cost allocation instruments were used, from the omnipresent full cost analysis, to the process and absorption costing. Suddenly, with the evolution in time of the firm, a particular instrument overcome the others, known as Activity-Based Costing or ABC.

The following figure represents the changes over time of the cost composition.

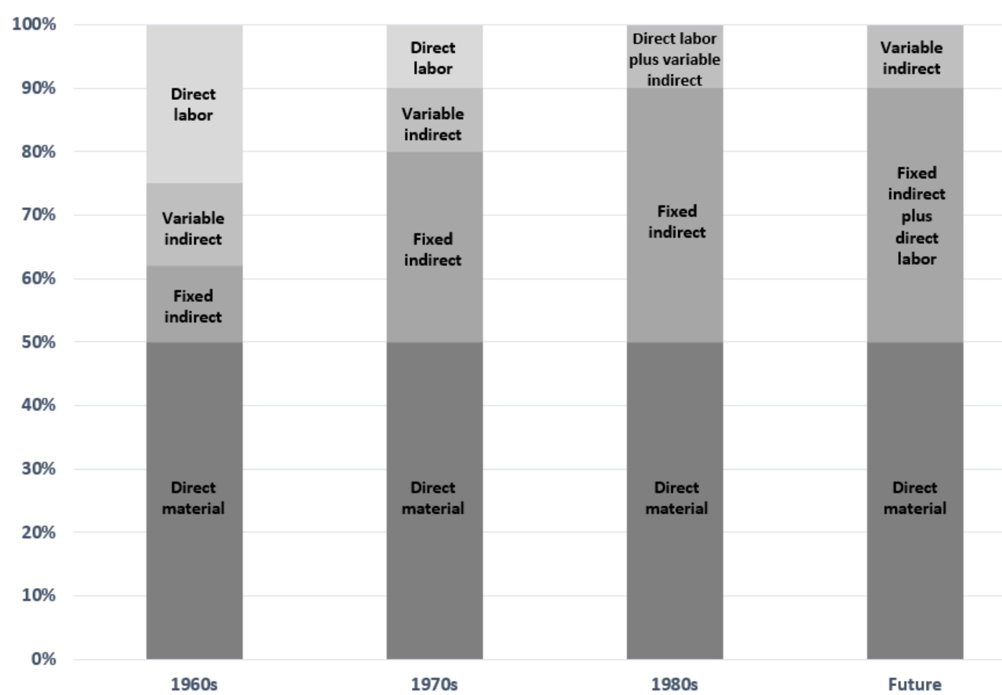


Figure 35 Changes of cost composition over time [108]

[108] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 108.

Note that is assumed for given a basic knowledge of the concept of direct costs, indirect costs, and some common cost allocation methods such as full cost.

As it is intuitable from the previous chart, the reasons behind this particular shift, has to be associated with the huge variation of the cost composition inside a firm. Where in the 60's the 25% of the costs are associated with the direct labor component, in the 80's only the 10% of the cost structure are associated with labor and variable indirect costs, a huge variation in a short amount of time.

ABC overcome this problem with a different approach to the cost allocation, this particular method consists in the allocation, for each cost object, of a specific amount of indirect costs, generated by a series of different activities, using as a measure unit a cost driver for each activity.

The following figure should better explain the concept.

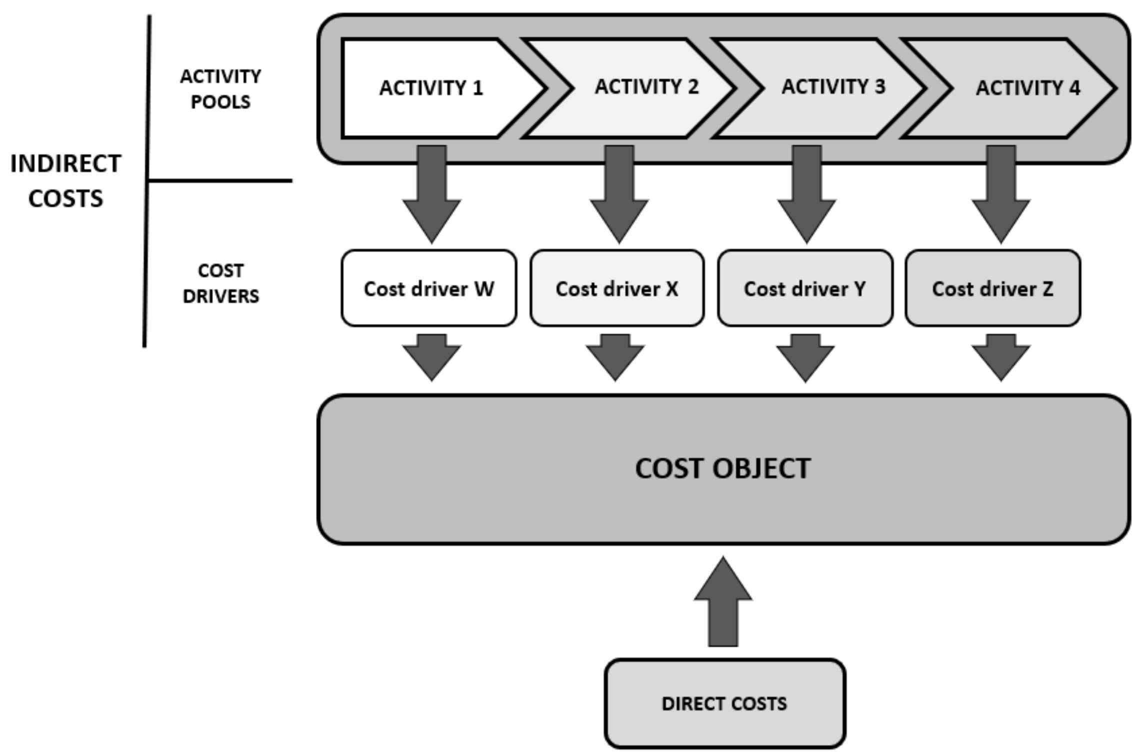


Figure 36 ABC cost structure

Differently from the older methods, ABC enhances the costing process in three different ways. First of all, allocate cost to different cost pools characterized by different activities. Secondly, changes the nature of some indirect costs, making them directly traceable to certain activities. Lastly it generates specific bases dedicated to the assignation of overhead costs to a certain cost object.

Obviously, ABC it is not the only instrument used, as a matter of facts the cost allocation method is strictly correlated with the structure of the firm, and consequently of the industry in which the firm operate.

4.2.2. Short-run decision-making

Before starting with the discussion, it is necessary to give some definitions about costs. From a behavioral stand point it is possible to outline three common typologies of costs:

- Fixed costs;
- Variable costs;
- Mixed costs;

Fixed costs

A cost can be considered fixed if, for a defined amount of time, it does not change in response to variations in the level of activity.

It is possible to further divide this typology of cost in the following three categories:

- Committed costs;
- Managed costs;
- Programmed costs.

Committed costs – Committed costs are a particular type of costs strictly correlated with the physical existence of the firm, and on which the manager has little or no control at all.

Managed costs – These types of costs are connected with the current operations of the firm, for this reason they are necessary for the survival of the operating existence of the firm.

Programmed costs – Programmed costs are totally, or almost totally, subject to management discretion and control, but are unrelated with the operating activities.

Variable costs

Variable costs are a particular type of costs that changes in correlation to a change in the level of activity.

Mixed costs

Lastly, mixed costs are a hybrid between fixed and variable costs. These costs can assume various shapes, and can be treated as totally fixed, totally variable costs, or divided, depending on the degree of variability and peculiar characteristics of the cost.

The following figure graphically represents the previously defined cost typologies.

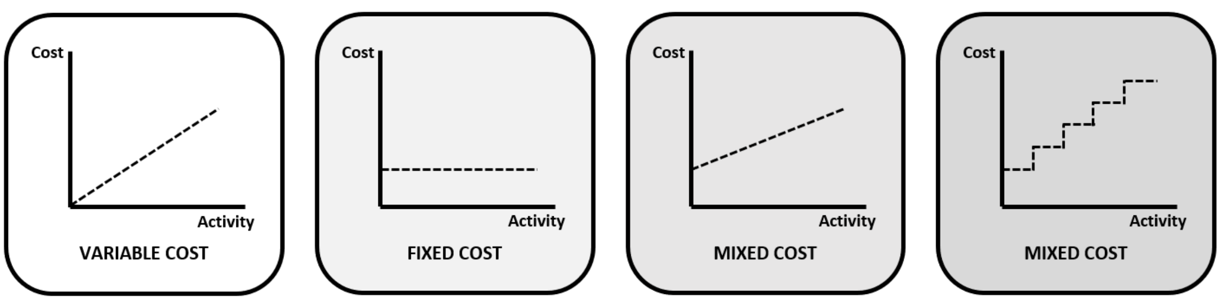


Figure 37 Cost behavior patterns

Note that these are not the only existing variants as it is possible to find also other variants of costs such as sticky costs.

As regards the feedforward short-period decision-making there are two main instruments used to help the decision process:

- Cost-Volume-Profit (CVP) analysis;
- Differential costs and revenue analysis.

Cost-Volume-Profit analysis

The purpose of CVP or Cost-Volume-Profit analysis "is to enable management to select the most desirable operating plans for achieving the enterprise's profit objective -- under the circumstances foreseeable at the time the decision is to be made. Indeed, CVP analysis can be viewed as a way of translating a given objective (e.g. profit level) into a more operational subobjective (e.g. sales volume), and thus aids planning considerably."[109]

Usually this type of analysis is correlated with two different graphs:

- Profit chart (or Break-even graph);
- Profit-volume chart.

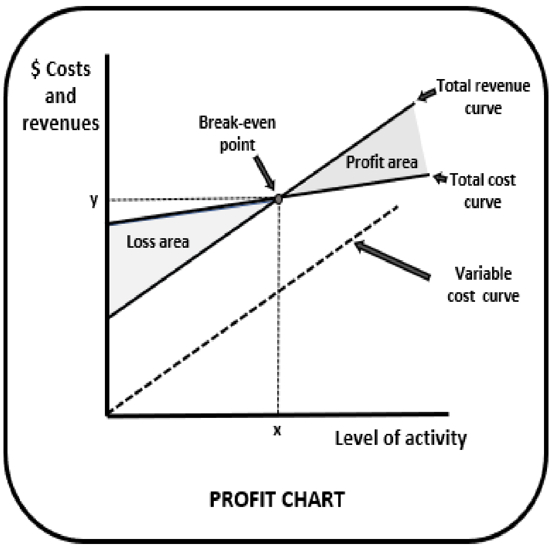
Profit chart – The purpose of this particular type of chart is to make a comparison between revenue and the relative costs for different levels of activity, highlighting variation in the profit. The second name of this graph outline an important concept, Break-even point, that need a definition. A break-even point is a particular point in the profit chart that indicates at which level of activity x the revenue y is equal to the sum of fixed costs plus variable costs connected with that particular level of activity.

Profit-volume chart – Differently from the previous one, the profit-volume chart has, as a Y axis, the total profit. Here the Total revenue minus total cost curve starts from minus fixed costs, in this manner, the curve crosses the 0-profit mark at the break-even point. This

[109] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 108.

representation is useful as it makes easy to spot the break-even volume and evaluate the relation between volume and wanted profit.

The following figure has the purpose to give an example of both types of graphs.



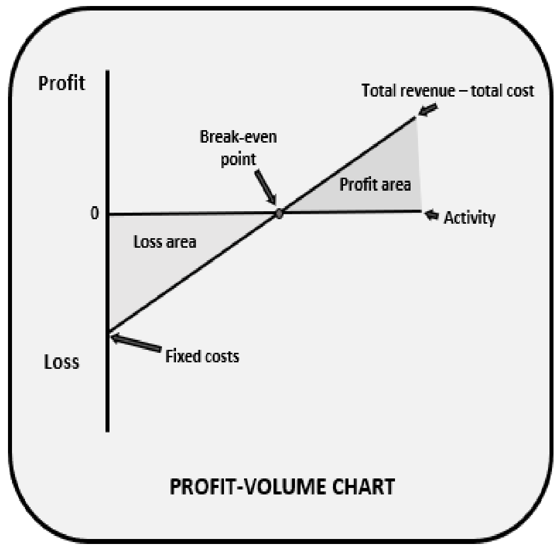


Figure 38 CVP instruments charts [110]

It is important to notice that the concept of fixed cost and consequently these graphs can be considered valid only under a specific relevant range. This because fixed costs are fixed not only in relation with time (what can be considered fixed cost in a short-term period, maybe cannot be considered fixed in a long-term one) but also in relation to the level of activity connected to these costs.

110 Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 108.

At this point, before defining the break-even formula, it is necessary to introduce another fundamental concept, the Contribution Margin ratio. This particular ratio can be defined as the difference between the selling price of a product and its variable cost.

Once defined the contribution margin, intuitively, the break-even point can be calculated with the following formula.

$$Break - even\ point = \frac{Fixed\ costs}{\left(\frac{Sales\ revenue - Variable\ costs}{Units\ Sold}\right)} = \frac{Fixed\ costs}{Contribution\ Margin\ ratio}$$

Differential costs and revenue analysis

Form a decision-making point of view, the differential cost and revenue analysis results a more useful approach. This because in this particular type of analysis a comparison between future costs (and revenues) of different courses of action is made. It is important to notice that in this analysis only the relevant costs and revenues are compared, where for relevant are intended costs and revenues that are influenced in the various courses of action. This is needed to avoid interferences due to, as an example, sunk costs.

Before concluding the discussion about short-term decision-making, it is important to remark that all the instruments discussed in the second chapter (LP models, Risk and Uncertainty instruments and criterion, etc.) are active components in all of the topic discussed in this chapter.

"It should be remembered that there is rarely a single correct answer to the decisions required by managers. What is important is that the data available are analyzed correctly and presented in a form which managers can use. It is therefore crucial that the management accountant provides that information in the form required and that managers are aware of their information needs in specific circumstances."[111]

4.2.3. Long-run decision-making

The first things that came in mind talking about long-run decision-making is strategy and strategic decision-making.

Generally speaking, long-run decision-making can be considered as a totally different species form the short-run decision-making for three different reasons: fewer constraints, greater attention on non-routine decisions, greater need for judgment within the decision-making process. The previously defined three elements leads to a generation of a particular environment, where risk, uncertainty and the level of resolution play a big and fundamental role.

Generally speaking, as regards the long-run decision-making, it is possible to outline two different categories:

- Investments decisions;
- Quantitative policy decisions.

Investments decisions

Investments decisions are a particular type of long-run decisions where an initial monetary amount is invested in the first period with the hope of receiving a series of benefits, usually monetary benefits, in a second period.

Quantitative policy decisions

Quantitative policy decisions differ from the investments one as it is connected with a variation of the policy or, a course or principle of action adopted or proposed, that change the rules that shapes the long-term environment of a particular firm.

[111] Coombs Hugh, Hobbs David, Jenkins Ellis, Management Accounting: principles and applications, Sage Publications Ltd, 2005, pg. 249.

Note that only the investment related decisions will be discussed in this paragraph.

Before shifting the attention towards the investment related decisions, it is useful to give a brief definition of the environment that surround the strategic problem-solving process. This particular process can be fragmented in three different components:

- Strategic analysis;
- Strategic choice;
- Strategic implementation.

The following figure represents the relations between these three elements.

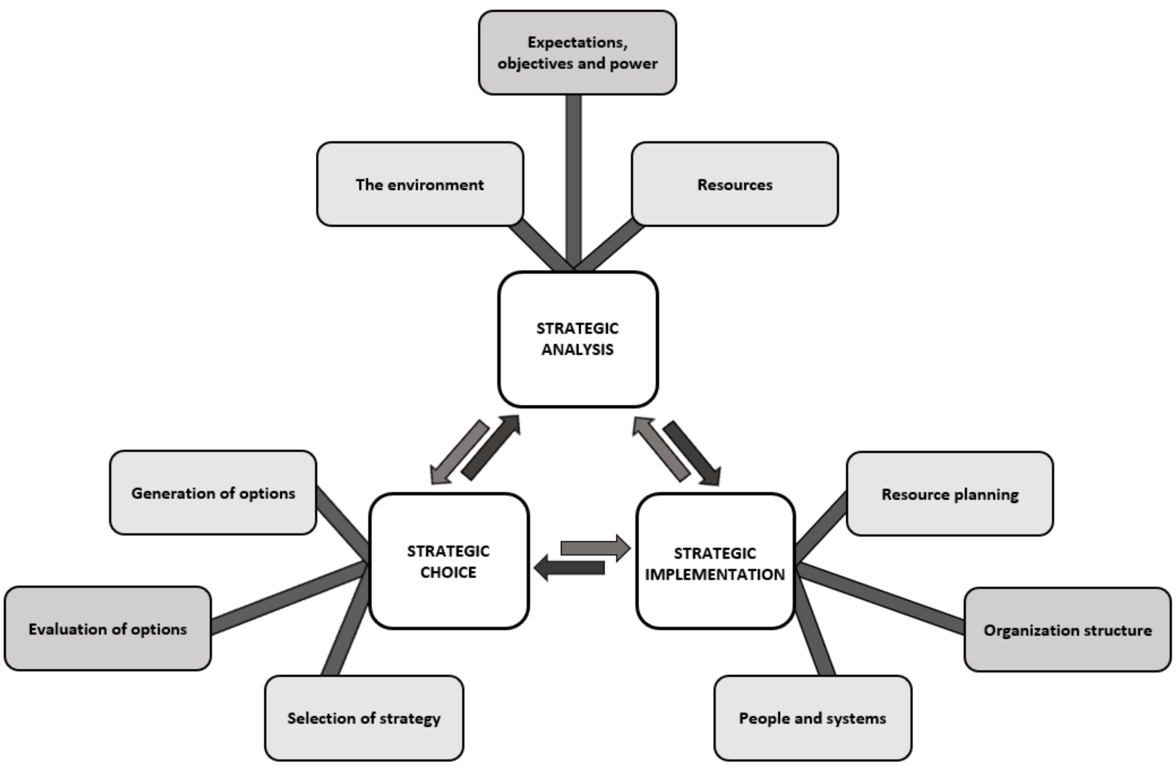


Figure 39 Summary model of the elements of strategic management [112]

[112] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 164.

Strategic analysis

Strategic analysis is focused around the understanding of the strategical position of the firm. This comprehend the analysis of the environment, and the analysis of the resources, expectation and power allocation.

Strategic choice

Strategic choice defines the typical decision-making steps with a strategic approach, the main elements are the generation of strategic options, the evaluation of these options, and finally the selection of the preferred one.

Strategic implementation

As regards the strategic implementation aspect, it is focused around the transition between decision and action. Here resource, people, and organization structure are the main instruments towards the effective application of a decision.

Once defined the strategic problem-solving it is now possible to shift the attention towards the investment topic.

"Firms often express their long-term strategic aim in a variety of different ways. […] Whether disclosed or not, firms must find ways of converting their broad statements of strategy and objectives into more specific and more operational aims. The commitments to particular objectives must be translated into operating activities. The modern, competitive firm is continually on the lookout for opportunities which are consistent with its strategy, and the stage of evaluating the financial costs and benefits of opportunities which meet strategic objectives may in fact be of a relatively low level of importance in the investment decision process."[113]

The following figure represent a possible five stages procedure for the investment decision process.

[113] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 256.

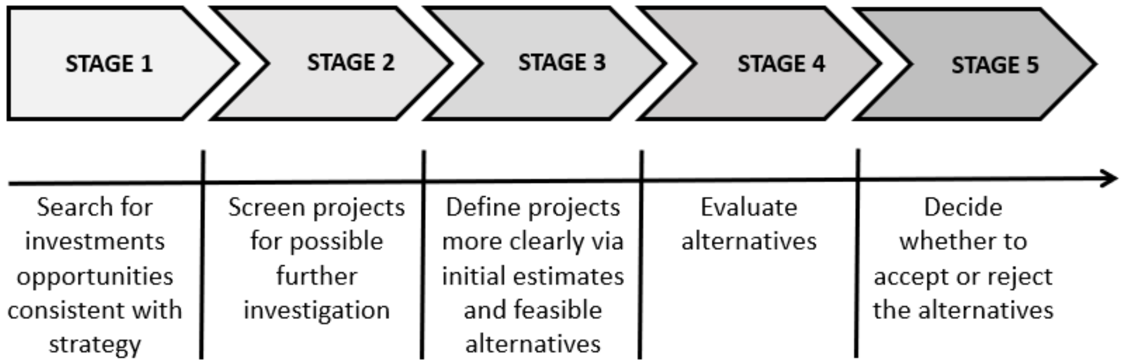


Figure 40 The investment decision process [114]

As regards long-term investments, the first, and most common, instrument used to evaluate if an investment is, or can be, profitable or not is the Net Present Value or NPV. The particular procedure connected with this instrument is made by the following three basic steps:

- Estimate the timing and the amount of the future cash inflow and outflow for each alternative;
- Discount each obtained cash flow with the relative and appropriate discount rate;
- Chose the best alternative with the NPV method.

Timing and cash flow estimation

This first step does not need a deep discussion. The first goal of this step is to define the timeline of each cash inflow and outflow for all the possible alternatives. Here, two important factors that have to be considered are the risk and uncertainty elements, as not all the cash flows could be certain, and also the correct date of the inflow and outflow is not. Note that usually all the cash flows are collapsed in clusters with the duration of one year each.

[114] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 257.

As regards the second goal, or the estimation of the cash flow, is important to include all the relevant cash flows for the considered alternative (as an example this can include: all the relevant operating cash revenues and costs, change in taxation, new investments granted). Here, for each cluster, the net income is calculated. Also, with this element uncertainty and risk play a big role, as a matter of facts usually the cash flows are the weighted average of the possible variants for a determined cash flow.

Cash flow discount

This second step is a little bit more complicated in comparison to the first one as its goal is to define the appropriate discount rate, also defined as cost of capital, for the future cash flows.

The cost of capital is composed by two different but fundamental elements:

- Equity capital;
- Debt capital.

Equity capital – As regards the cost of the equity capital it is possible to outline two most widely spread calculation models:

- Dividend growth model;
- Capital Asset Pricing Model (CAPM).

For the dividend growth model, the value of equity capital is defined as the present value of the future dividend stream, consequently, it is possible to calculate it using the following formulas:

Constant dividend

$$K_E = \frac{d}{V_E}$$

Incremental dividend with a constant per annum rate (g)

$$K_E = \frac{d_1}{V_E} + g$$

Note that: K_E = the cost of equity capital; d = the dividend paid; V_E = is the present value of equity capital.

As regards the CAPM model the logic behind the calculation of the cost of capital is totally different from the previous one. "Here the cost of equity capital is calculated by reference to the return required in a single period by the company's investors. This return comprises two elements – an element which is risk free and thus represent a fixed minimum level of return, and an element (or premium) which depends on the relative risk associated with the performance of the company's shares"[115]

With this method, the equity capital can be calculated using the following formula:

$$K_E = r_f + (r_m - r_f)\beta$$

Note that: K_E = the cost of equity capital; r_f = return on a risk-free security (e.g. treasury bills); r_m = return on market portfolio; β = variability of the firm's return in relation with that specific market portfolio.

It is important to notice that both instruments are based on assumptions (such as in the case of the market portfolio value), and for this reason, they are not perfect instruments.

[115] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 264.

Debt capital – The cost of debit capital is easier to calculate as the information about the interest rate for the capital acquired is easy to access as predefined in the contract.

Consequently, the debit capital can be calculated with the following formula:

$$K_D = \frac{C}{V_D}$$

Note that: K_D = the cost of debit capital; C = annual interest paid; V_D = is the present market value of debit capital.

The last step needed for the definition of the discount rate consists in the calculation of the Weighted Average Cost of Capital (WACC). Intuitively, its purpose is to define a weighted average between the two possible sources of capital for the firm.

WACC can be calculated with the following formula:

$$WACC = \left(K_E \times \frac{V_E}{V_T}\right) + \left(K_D \times \frac{V_D}{V_T}\right)$$

Note that: V_T = total market value of debit and equity; V_E = total market value of equity; V_D = total market value of debit;

NPV method application

The last step can be considered the easiest one, once discounted each future cash flow it is now possible to apply the NPV decision rule, that consists in choosing the alternative with the highest NPV value. It is necessary to remember that a sensitivity analysis is mandatory as an NPV highly sensitive to errors can corrupt the results, increasing the possibility of taking a bad decision.

It is also important to remember that long-term decisions are susceptible to the effect of inflation, in this scenario the real discount rate can be calculated as follow:

$$K = \frac{i - h}{i + h}$$

Note that: *K* = real discount rate; *i* = obtained discount rate; *h* = expected rate of inflation;

The NPV method can be considered as the most accurate existent method dedicated to the evaluation of an investment, but it carries a huge limiting factor, it requires a lot of time to be implemented, and in a managerial context time is a scarce resource.

For the previous, and also other, reasons it is useful to discuss about some others, equally valid, methods dedicated to the evaluation of an investment. These instruments are the following:

- Internal Rate of Return (IRR);
- Payback method;

Internal Rate of Return

The IRR method can be considered as strictly connected with the NPV. As a matter of facts, the internal rate of return represents the specific rate of return in which the sum of all the discounted future cash flows is equal to the initial investment, or the discount rate at which the resulting NPV is equal to zero. With this method a project is acceptable if its IRR is greater than the IRR of the others alternatives.

Talking about IRR it is important to outline two important things: the first one is that the only way to calculate this rate is with a trial and error process (statement valid also in a scenario where the process is done by a machine). The second thing is that the IRR method does not account for size of the cashflow, and, as a consequence, over a certain discount rate, it could outline a certain investment, with a higher IRR but with a lower tangible NPV.

Payback method

The payback criterion is a very simple investment valuation method, differently from NPV and IRR it can be classified as a non-discounting method. The underlying concept of this criterion is to accept a particular investment if the estimate of the period in which the initial investment is payed back is smaller than in the other alternatives.

Intuitively, this simple criterion brings some problems, over the previously citated non-discounting technique, first of all it ignores all the cash flows arising after the payback period. Secondly, it ignores the timing in which the cash flows are positioned in the payback period.

In conclusion, it is possible to say that, knowing the possible problems connected with this method, "it may be easy, and not too misleading, to apply it to small investment projects where the prediction of longer-term cash flows is not critical to the acceptance decision, or where the pattern of later cash flows is assumed to be similar to that of early years."[116]

Note that, to remove the problem of timing in the payback period, it is possible to adapt the payback method to take account of the time value of the cash flows, in this scenario the method is called discounted payback.

4.2.4. Standards and estimates

In the feedforward control process standards and estimates are two, very important, elements.

[116] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 295.

As regards the cost subject, estimates can be defined as an approximation of the cost of inputs of an operation, project, product and so on.

It is possible to define two different approach for estimation process:

- Industrial engineering approach;
- Historical cost information approach.

Industrial engineering

The first cost estimation approach that will be discussed is the industrial engineering one, in which, intuitively from the name, the person that make the estimate is usually an industrial engineer. As regards direct costs the estimate of the cost of direct material and labor can be based on the prototype and on timing test. Intuitively from the methodology, indirect costs are hard to predict as there are no previous records and consequently any estimates made can deviate a lot from the real cost.

This method results very useful in three different scenarios: when the relationships between input and final product are simple, when the cost composition is made almost entirely by direct costs, lastly, and more commonplace, when there are no records on which estimates can be based.

Historical cost information approach

As regards the cost estimation based on historical data, it is possible to outline four different methods:

- Account inspection method;
- Visual fit method;
- High-low method;
- Simple linear regression;

Account inspection method – In this first estimation method the estimate is made by the management accountant. Here the accountant has the role to inspect the data gathered by the accounts related with certain process, with the purpose of defining the nature of the cost (fixed, variable, mixed, etc.) and then estimate the costs for the future.

A first downside of this method is that it requires that the information registered are accurate and representative of the costs of the process. A second downside is that a correct definition of the nature of the cost it is not always immediate and easy.

Visual fit method – The concept underlying this second estimation method is very simple, with the help of a scattergram (a particular chart composed by various points made by the relations between the costs obtained by the historical information and the relative level of activity) a pattern for the behavior of the costs is outlined.

Note that this method is very fast in the implementation, but also very imprecise, as there is no certainty that the traced line effectively represents the behavior of those costs.

High-low method – Similarly to the previous method, the high-low method is based on the use of a scattergram. In this case a line is traced starting from the point with the lowest level of activity, to the point with the highest level of activity.

Simple linear regression – Differently from the previously discussed methods, this particular method provides more rigorous information about the behavior of the costs. This method is based on a simple, but powerful instrument, known as simple linear regression. "A regression equation seeks to estimate a relationship between a dependent variable (usually costs) and one or more independent variables (such as level of activity, for example, claims processed or machine hours used) by using past observations. Linear regression assumes a linear relationship between the independent and the dependent variables."[117] The result of this technique is to obtain more objective information reducing the presence of the omnipresent human error.

[117] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 216.

Once discussed some methods and instruments related with the generation of estimates it is now possible to shift the attention towards standards.

Standards can be defined as predetermined or current estimates of inputs and outputs. It is possible to outline two different categories of standards:

- Manufacturing standards;
- Non-manufacturing standards.

Manufacturing standards – In a manufacturing environment, standards are defined for the basic input variables used in the production process (as an example direct material and direct labor).

Non-manufacturing standards – Also if, in general, standards are mostly used in a manufacturing environment, it is also possible to set standards for non-manufacturing activities (such as number of words per minute, number of questionnaires decoded, and so on).

Note that setting standards for non-manufacturing activities can be difficult as there are many factors that can influence an activity. Another obstacle in the setting non-manufacturing standards is the possible presence of quality activities, as an example, an efficient measure of inputs and outputs can be very difficult.

Standards are a powerful instrument to optimize and maximize the efficiency of a process but, similarly to other instruments, they present some drawbacks.

First of all, a standard, in general, should not be set neither too slack nor too difficult, this because, intuitively, slack standards reduce the efficiency of the process and unobtainable standards can, as an example, generate a lack of motivation and also frustration.

Another important element to bear in mind in the definition of a standard is the learning effect, that can be defined as the process by which the productivity increase as a consequence of the knowledge acquired through time in doing a particular task or activity. As a consequence of this effect standards need to be revised and adjusted from time to time to avoid a consequently reduction of efficiency.

4.2.5. Budgeting process

"The various activities within a company should be coordinated by the preparation of plans of actions for future periods. These detailed plans are usually referred to as budgets. Short-term planning or budgeting, […] must accept the physical, human and financial resources at the present available to the firm. These are to a considerable extent determined by the quality of the firm's long-range planning efforts." [118] As intuitable from the previous quote, also if the budgeting process can be considered a short-term instrument, it can also be considered a fundamental brick of the long-term planning, as it influences every activity in the firm, from the input, to the output and the acquired assets.

Another definition of the budgeting process can be the following "The general objective of budgeting is to provide formal, quantitative and authoritative statement of the firm's plans, expressed in monetary terms." [119] This definition outlines another particular side this process showing deeply the importance of this instrument.

The budgeting process is composed by the following eight different steps:

- Budget policy communication;
- Performance restricting factors;
- Sales budget preparation;
- Initial preparation of budgets;
- Budget negotiation;
- Budget coordination and review;

[118] Drury Colin, Costing, an Introduction: second edition, Chapman and Hall, 1990, pg. 359.
[119] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 313.

- Budget acceptance;
- Budget review.

Budget policy communication

The purpose of the first stage is to communicate the policy under which the budget should be based. These policies are generated as a consequence of the long-term plan of the firm as the resulting budget should follow, and moreover be part of, the long-term goal. It also outlines the managers responsible for the generation of the budget and some other general policies necessary to govern the process.

Performance restricting factors

In this second step all the performance restricting factors (in general this restricting factor is sales demand, but it is possible to have also other restricting factors such as production capacity) are determined.

Sales budget preparation

In the third step, the sales budget is prepared with the help of the volume of sales and the sales mix. This particular budget has the purpose of determining the level of operations for the firm.

Initial preparation of budgets

Intuitively for the name, in this particular step the designated managers, each one for its competing area, prepare the budget. Note that usually this step follows a bottom-top technique, this because, starting a budget from the lowest level of the management improve the possibility for the firm to reach the goals, and also facilitate the final acceptance of the cumulative budget.

Budget negotiation

As introduced before, “To implement a participative approach to budgeting, the budget should be originated at the lowest level of management. The managers at this level should submit the budget to their superior for approval. The superior should then incorporate this budget with others budgets for which he is responsible and this submit this budget for approval to his superior.

The manager who is the superior then becomes the budgetee at the next higher level." [120] For each of the previously defined stages the budget is negotiated and then eventually agreed between both parties.

Budget coordination and review

In the sixth step, for each stage of the negotiation process all the budgets must be examined and revised with each other to outline possible inconsistencies due, as an example, to budget out of balance. If a particular budget is rejected it need to be adjusted or corrected following again the entire negotiation process.

Budget acceptance

In the budget acceptance step, the final budget, also known as the master budget, is finally accepted by the top management. Once the master budget is accepted each budget fragment is passed down to its responsibility center to be applied and monitored.

Budget review

The last step of the budgeting process consists in the comparison of the planned budget with the actual budget results. This process needs to be actuated periodically to prevent possible negative derails from the planned budget. Note that this particular process can be also useful to have a periodical feedback for the performance of each responsibility center.

The following figure has the purpose to graphically outline the previously defined budgeting process.

[120] Drury Colin, Costing, an Introduction: second edition, Chapman and Hall, 1990, pg. 366.

Figure 41 Budgeting process

After defining the budgeting process, it is now possible to make a brief discussion about the purpose of the master budget and its composition.

"The need to prepare a master plan is usually cited as a prerequisite for the success. It is useful because […] it both sets out the organization's targets for the coming period in a quantifiable, easily to understood form, and provides a basis for co-ordinating the organization's detailed operating budgets, which are essential ingredients of the control process."[121]

[121] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 336.

It is possible to decompose the master plan in two different categories of budgets:

- Operating budgets;
- Financial budgets.

Operating budgets

Intuitively, this particular category contains all the budgets strictly connected with the operating element of the firm.

It is possible to outline four different budgets belonging to the operating category:

- Sales budget;
- Production budget;
- Capital budget;
- General and administrative budget.

The sales budget has the purpose to represent the revenue originated form a forecast of the demand. As regards the production budget, its purpose is to outline the various future requirements able to cover the desired quantity of goods that have to be produced. The capital budget is needed to outline the future expenditure in capital projects. Lastly, the general and administrative budget has the purpose to cover all the other operating aspects that lie outside the competences of the sales and production budgets.

Financial budgets

As regards the financial category, similarly to the previous one, it contains all the budgets related with the financial subjects of the firm.

It is possible to outline three different budgets belonging to the financial category:

- Cash budget;
- Budgeted balance sheet;
- Budgeted income statement.

The cash budget has the purpose to outline all the financing requirement for the predefined period. The budgeted balance sheet is concerned with the expression of the financial position of the firm for the end of the predefined period. Lastly, as regards the budgeted income statement, it can be considered as a summary of the operating budget previously defined.

The following figure represents the interconnection between the different types of budget that composes the master budget.

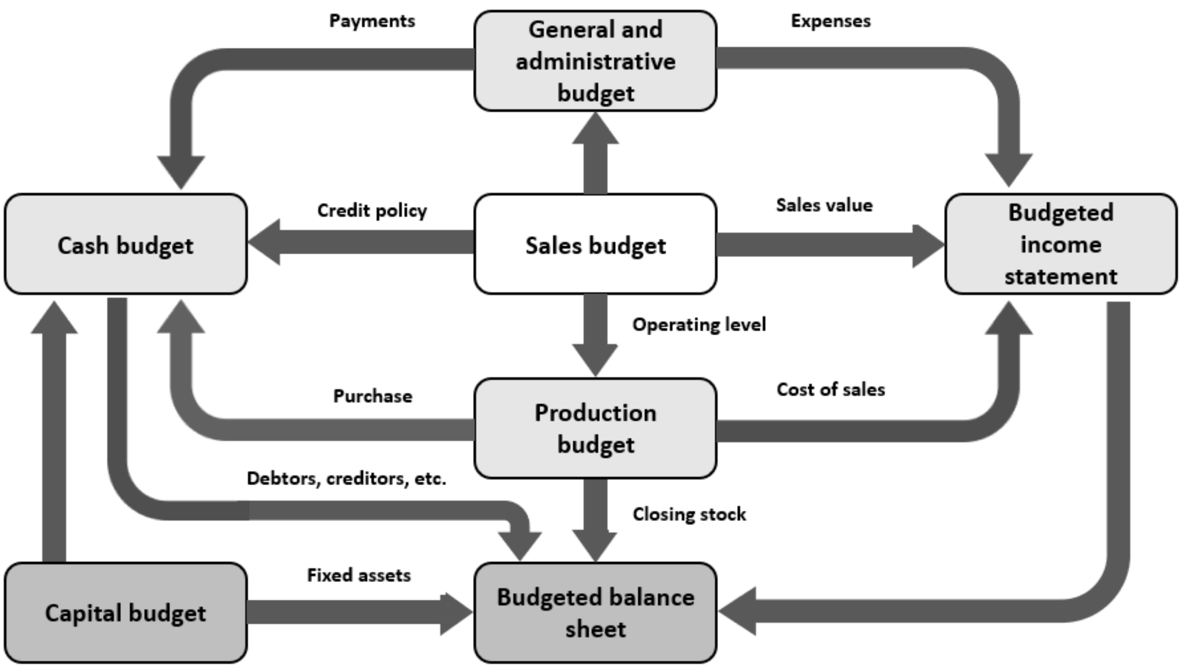


Figure 42 The relationship between budget statements [122]

[122] Arnold John, Turley Stuart, Accounting for Management Decisions: third edition, Prentice Hall Europe, 1996, pg. 337.

Note that the master budget will not be further discussed as a deepening do not complains with the subject of this particular thesis.

4.3. Feedback control and decisions

"There is an inevitable lag in feedback systems between outcomes and responses: while feedforward systems require proactive behavior, feedback systems rely on reactive behavior. In other words, feedforward systems anticipate the need for change whereas feedback systems adapt to change." [123]

4.3.1. Performance measurement

As regards the performance measurement of a predefined firm it is possible to outline two different, and also important performance instrument categories:

- Monetary performance measurement;
- Non-monetary performance measurement.

Monetary performance measurement

The monetary performance measurement can be considered the oldest, and more classic performance instruments set. This particular category is based on the evaluation of the performance by analyzing the difference between the standard cost and the actual one for a various series of elements. Note that standard costs differ from budgeted costs as the first one is referred to the cost expectations per unit of activity, as regards the latter it is referred to the cost expectation for the total activity.

[123] Wilson Richard M.S., Chua Wai F., Managerial Accounting: method and meaning, Chapman & Hall, 1993, pg. 280.

The fundamental brick that composes this category is the profit variance, this particular variance is then decomposed in a series of sub-categories and elements with the purpose of increasing the specificity of each sub-element and consequently the overall significance of the measurement.

The following figure has the purpose to clarify the interconnections between these different variances in the composition of the profit variance.

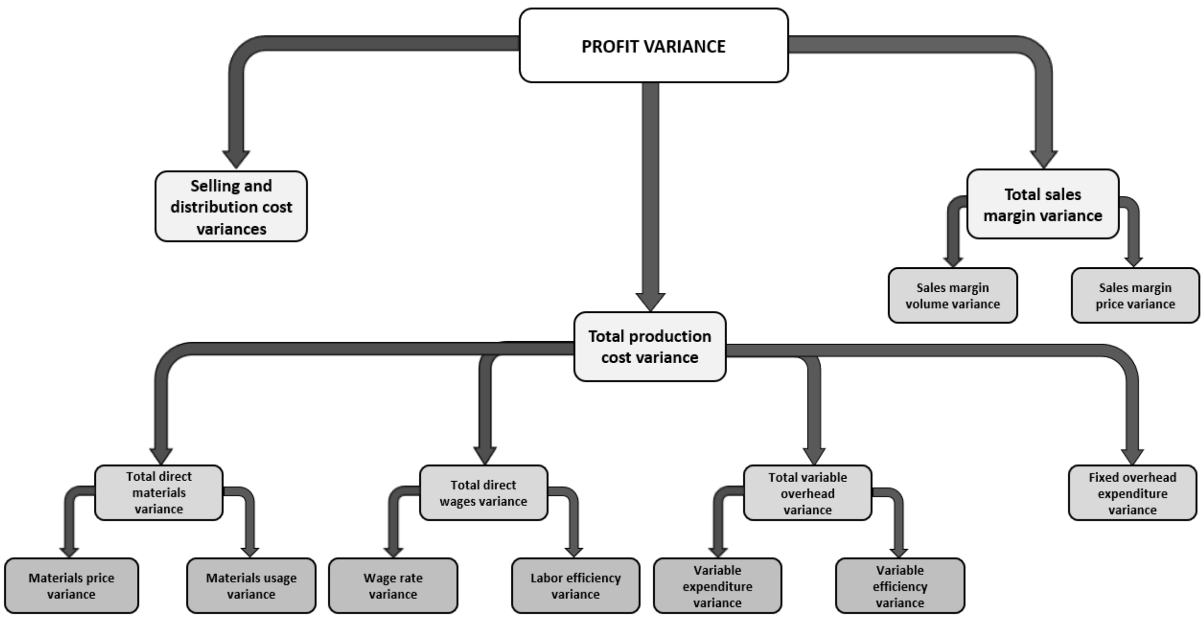


Figure 43 Variance analysis [124]

Note that the selling and distribution cost variances will not be discussed in this thesis.

As it is possible to see from the previous figure, in general, depending on the source and the year, it is possible to outline nine different basilar variances:

[124] Drury Colin, Management Accounting for Business: 6th edition, Cengage, 2016, pg. 310.

- Materials price variance;
- Materials usage variance;
- Wage rate variance;
- Labor efficiency variance;
- Variable expenditure variance;
- Variable efficiency variance;
- Fixed overhead expenditure variance;
- Sales margin volume variance;
- Sales margin price variance.

Materials price variance – The materials price variance has the purpose to outline the variance between the standard cost for one unit of input and the real cost at which that unit has been buy. This variance can be calculated with the following formula:

$$Material\ price\ variance = (SP - AP) \times AQ$$

Note that: *SP* = standard price; *AP* = actual price; *AQ* = actual quantity;

Materials usage variance – As regards the materials usage variance it has the purpose to define the difference between the standard and the actual quantity of input used to produce one unit of output. This variance can be calculated with the following formula:

$$Material\ usage\ variance = (SQ - AQ) \times SP$$

Note that: *SQ* = standard quantity; *AQ* = actual quantity; *SP* = standard price;

Wage rate variance – The wage rate variance can be defined as the difference between the standard wage and the actual wage payed for a specific number of hours worked. This variance can be calculated with the following formula:

$$Wage\ rate\ variance = (SR - AR) \times AH$$

Note that: *SR* = standard wage rate per hour; *AR* = actual wage rate per hour; *AH* = actual numbers of hour worked;

Labor efficiency variance – Intuitively, the labor efficiency variance represents the difference between the programmed required time to produce one unit of output and the actual one. This variance can be calculated with the following formula:

$$Labor\ efficiency\ variance = (SH - AH) \times SR$$

Note that: *SR* = standard wage rate per hour; *SH* = standard numbers of hour worked; *AH* = actual numbers of hour worked;

Variable overhead expenditure variance – The variable overhead expenditure variance has the purpose to compare the expected overhead expenditure with the actual one. This variance can be calculated with the following formula:

$$Variable\ overhead\ expenditure\ variance = \ BFVO - AVO$$

Note that: $BFVO$ = budgeted fixed variable overhead for the actual direct labor hours of input; AVO = actual variable overhead costs;

Variable overhead efficiency variance – The variable overhead efficiency variance represents the difference between standard hours of input and actual hours of input in relations with the standard overhead rate. This variance can be calculated with the following formula:

$$Variable\ overhead\ efficiency\ variance = \ (SH - AH) \times SR$$

Note that: SH = standard hours of input; AH = actual hours of input; SR = standard variable overhead rate;

Fixed overhead expenditure variance – The fixed overhead expenditure variance can be considered as the difference between the budgeted fixed overheads and the actual one, it is mandatory to outline that this variance is totally independent from the firm object of analysis. This variance can be calculated with the following formula:

$$Fixed\ overhead\ expenditure\ variance = \ BFO - AFO$$

Note that: BFO = Budgeted fixed overheads; AFO = actual fixed overhead;

Sales margin volume variance – Intuitively, the sales margin volume variance has the purpose to outline the variation between the planned sales volume and the actual one. This variance can be calculated with the following formula:

$$Sales\ margin\ volume\ variance = (AV - BV) \times SM$$

Note that: AV = actual sales volume; BV = budgeted sales volume; SM = standard contribution margin;

Sales margin price variance – Lastly, the sales margin price variance outlines the difference between the actual selling price and the planned one in reference to the actual sales volume. This variance can be calculated with the following formula:

$$Sales\ margin\ price\ variance = (ASP - SSP) \times AV$$

Note that: ASP = actual selling price; SSP = standard selling price; AV = actual sales volume;

As regards the sales margin variance it is necessary to outline that "it is not very meaningful to analyze the total sales margin variance into price and volume components, since changes in selling prices are likely to affect sales volume. […] It may be unrealistic to expect to sell more than the budgeted volume when the selling prices have increased. A further problem with sales variances is that the variances may arise from external factors and may not be controllable form the management" [125] For the reasons outlined form the previous quote many other sales variance

[125] Drury Colin, Management Accounting for Business: 6th edition, Cengage, 2016, pg. 310.

divisions have been proposed in time, one of them is the differentiation in market size and market share variance, and product mix and sales price variance.

Note that all the previous variances have as a reference point for the standard cost a flexible budget (a particular type of budget that adjust or flex in concomitance with a change in the level of activity).

It is necessary to remark that this is not the only possible division of variances, this variant has been proposed as it is the most common and generally accepted one.

Non-monetary performance measurement

"I sistemi tradizionali di reporting dei risultati economici di un'azienda, sia destinati all'interno (budget o analisi delle variazioni di budget), sia all'esterno (conto economico o rendiconto finanziario), ricordano molto il tabellone con i punteggi di un incontro. Il tabellone segnala al giocatore che lo guarda se la sua squadra sta vincendo o sta perdendo, ma gli dice molto poco riguardo alla qualità del suo gioco: quindi non è guardando il tabellone che il giocatore potrà giocare bene." [126]

As it is possible to guess from the previous quote, the use of traditional performance measurement indicators can be considered a valid instrument up to a certain point, then, after that, it is mandatory to move towards new measures. This is necessary as the traditional instruments are not able to address a series of common, and also important, issues such as: quality, productivity, on-time delivery, innovation, teamwork, flexibility, short cycle times, closeness to customers, and so on.

The following performance measurement implementation process is adapted from: Maskell Brian H., Making the Numbers Count: second edition.

To successfully implement in the company a new performance measurements criterion it is possible to outline a series of required steps:

- Write a strategy;
- Set goals and objectives;

[126] Shank John K., Govindarajan Vijay, La Gestione Strategica dei Costi: contabilità direzionale e vantaggio competitive, Il Sole 24 Ore Pirola S.p.a, 1996, pg. 162.

- List the Critical Success Factors (CSF);
- Validate the Critical Success Factors;
- Link CSF to Value-streams and other key processes;
- Key measures development;
- Plot new performance measures;
- Expand performance measures.

The following figure has the purpose to give a representation of the process.

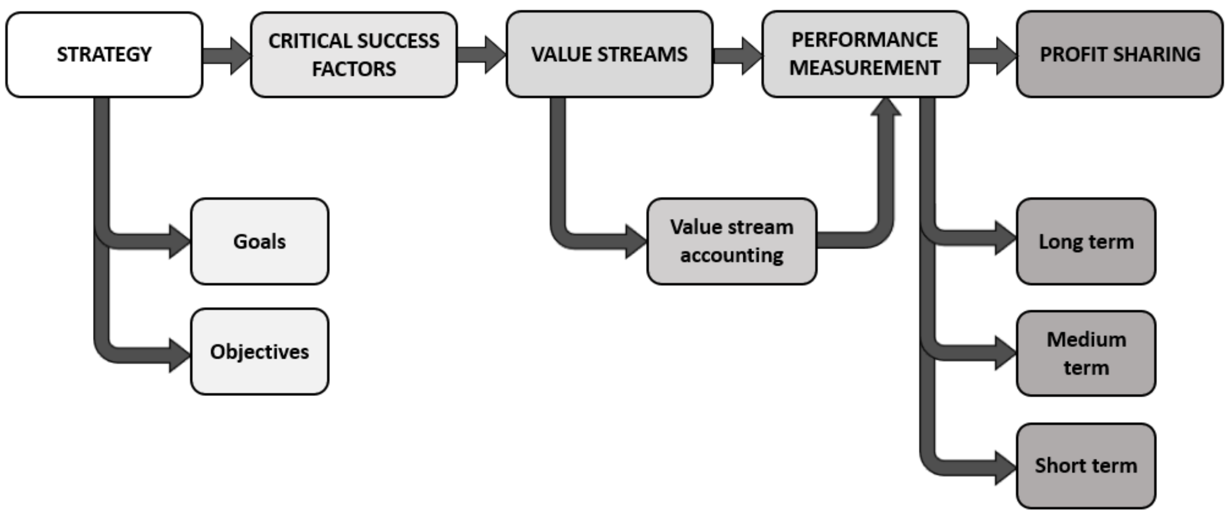


Figure 44 Development of strategy-based performance measurement [127]

1 Write a strategy – The first step in the implementation of a new set of performance measures is to define the strategic issues of the firm. This is needed as it permits to understand the direction of the firm and consequently generate a coherent set of measures.

[127] Maskell Brian H., Making the Numbers Count: second edition, Taylor and Francis Group LLC, 2009, pg. 155.

2 Set goals and objectives – As a consequence of the first step, in this particular step a series of goals and objectives coherent with the strategy are outlined. “Objectives state the qualitative direction in which the company wishes to go, and the goals state the quantitative outworking of those objectives.” [128]

3 List the Critical Success Factors (CSF) – Intuitively form the name, the third step consists in the definition of the CSFs.

4 Validate the Critical Success Factors – Once defined a series of Critical success factors the next step is to validate them. This is necessary as it is not obvious that each one of them can be applied within the company.

5 Link CSF to Value-streams and other key processes – In the fifth step the CSFs are linked with related the strategic processes of the company, as a single CSF can be useful to monitor more than one single process.

6 Key measures development – The sixth step is the most complex one, as its purpose is to effectively develop all the necessary performance key measures for every level of company.

7 Plot new performance measures – The seventh step consists in testing the new measures in a plot area of the company. This has the purpose to test the efficiency and effectiveness of the new performance measures, avoiding possible irreparable damages.

8 Expand performance measures – Lastly, in the eight step the previously tested and verified performance measures are finally applied to the entire company.

In conclusion, it is possible to outline a series of pros and cons to the use of these particular indicators. Differently from the monetary measures, as a consequence of their generation process,

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[128] Maskell Brian H., Making the Numbers Count: second edition, Taylor and Francis Group LLC, 2009, pg. 154.

the non-monetary ones are more connected with the effective strategy of the company. A second point in favor is the easy understandability of the cause effect relationship for certain variations in the measures. As regards the negative side "Oltre alle difficoltà di legare logicamente tra loro quantità monetarie e non monetarie, le maggiori difficoltà derivano principalmente dal conflitto insito nella diversità di orizzonte temporale delle misure monetarie rispetto a quelle non monetarie e alla confusione che ne può derivare." [129]

4.4. An analysis of Value-Based Management decisions

The following discussion on Value-Based Management as regards the decision-making process is mostly adapted from: Knight James A., Value Based Management: developing a systematic approach to creating shareholder value.

The purpose of this paragraph is to give a different view point on the previously discussed arguments, shifting the perspective towards the conception of a firm as a living structure which purpose is not to generate revenue but to generate value.

"Managing for value is nothing new. […] Value management is a way of focusing managers on the company's strategy, to achieve better alignment, and create value. Managing for value means using the right combination of capital and other resources to generate cash flow from the business. Value management is not an event that occurs once a year but is an ongoing process of investing and operating decision making that includes a focus on value creation" [130]

Intuitively form the previous quote, Value based-management is strictly connected with the decision-making process and, consequently, its main concrete action tools. To better outline this concept the following figure has the purpose to represents how the key management processes can reinforce the key stages of Value-Based Thinking.

[129] Shank John K., Govindarajan Vijay, La Gestione Strategica dei Costi: contabilità direzionale e vantaggio competitive, Il Sole 24 Ore Pirola S.p.a, 1996, pg. 162.
[130] Knight James A., Value Based Management: developing a systematic approach to creating shareholder value, McGraw-Hill, 1998, pg. 101.

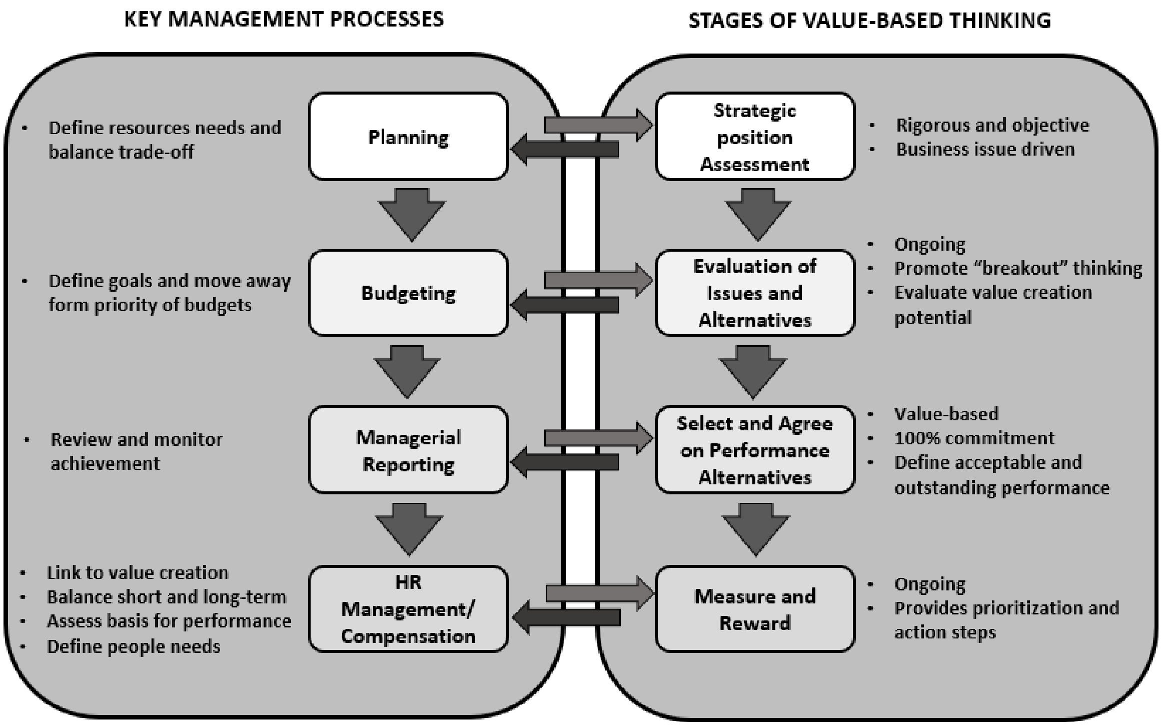

Figure 45 Relationship of management processes to Value-Based Thinking [131]

From the perspective of the decision-making process, intuitively, Value-Based Management can improve the decision-making process by acting as follows on his three fundamental elements:

- Objectives;
- Alternatives;
- Information.

Note that this is another possible variant on the separation of the fundamental elements of decision-making.

[131] Knight James A., Value Based Management: developing a systematic approach to creating shareholder value, McGraw-Hill, 1998, pg. 103.

Objectives

Usually, in the decision process of a firm, managers make trade-off in the in the choice for a valid alternative between conflicting objectives. In this particular scenario, managing for value can maximize the value for the organization by giving a weighting scale to compare these objectives.

Alternatives

"Often, the alternatives examined in the decision-making process are too narrowly focused on the existing way of doing business. Managing for value can introduce the discipline of expanding the decision making to encompass a broader range of alternatives" [132] Intuitively, this means that managing for value can improve the decision-making process by increasing the total number of alternatives.

Information

Lastly, Value-Based Management can improve the information that the managers receive by increasing its quality, this happen because managing for value needs a series of specific and unique information about the environment that surround the decision.

Mowing towards the key management processes perspective, Value-Based Management can improve each one of the following fundamental processes by acting as follows:

- Planning;
- Budgeting;
- Reporting;
- Compensation.

[132] Knight James A., Value Based Management: developing a systematic approach to creating shareholder value, McGraw-Hill, 1998, pg. 105.

Planning

The planning activity revolves around the concept of taking all the information about the current activity of the company, in addition with a certain dose of assumption on the future and knowledge form inside and outside the company, with the purpose of generating a specific plan for the future. The use of value can improve the planning process as it is possible to produce a plan based on a higher number of alternatives, consequently, with a higher chance to generate a more valid, pondered, and comprehensive result.

Budgeting

As said before, the budgeting activity is a short-term procedure in which capital and commitment are enchanneled to obtain close operating results. Here Value-Based management can improve the process as it shifts the attention towards a value vision, and not to a monetary vision during the resource allocation process, leading to an improvement of the shareholder's value.

Reporting

"The old truism states, "What gets measured gets done." Management reporting is the measurement of what gets done. Value measures can be used in reporting to reinforce the managing-for-value message."[133] There are two categories of managers, short-term managers and long-term ones, that carries respectively a short-term decision-making vision and a long-term one. It is in the first category that value management can improve the reporting process by forcing a long-terms vision, that, for various reasons (as an example the fact that investments initiatives pay off during a longer period that the budget one), it is strictly connected with the value of the business.

Compensation

The last process to be discussed is the compensation one. In this scenario, value-based management can help the process as it shifts the attention towards the use of more objective and

[133] Knight James A., Value Based Management: developing a systematic approach to creating shareholder value, McGraw-Hill, 1998, pg. 118.

value-directed performance measures. This leads to compensate with a higher amount value creating processes, with the consequence of boosting value-creating decision-making.

In conclusion "Value management is a powerful tool. When used correctly to focus managers, it will drive dramatic improvements in decision making. However, like any other tools, it can be misused."[134] It is possible to say that the previous quote outlines the essence of this particular instrument. As seen in the previous discussion, the proposition for value in a manager, if done correctly, can improve both the key management processes and the decision at the origin of these processes, leading to a better outcome.

[134] Knight James A., Value Based Management: developing a systematic approach to creating shareholder value, McGraw-Hill, 1998, pg. 297.

CHAPTER 5

Conclusions

During this thesis the entire decision-making process has been discussed with all the connected aspects and facets from a managerial perspective.

In the first chapter the discussion has settled on a general introduction to the main topic with a description of the generic exoskeleton of a decision-making process and, subsequently, with a general introduction of the main hindrances, categorized as: information, time, objectives, risk and lastly the worst of all, mankind.

The second chapter has been focused on the discussion about the role of the mathematic domain as a support instrument for the decision. Starting from the main interconnection between the two worlds (mathematic and managerial) usually occupied by the modeler, an entity which role is to translate part of the main problem in a mathematical form, free of bias, and translating back the possible solutions.

Subsequently the discussion has shifted towards the definition of a series of mathematical instruments with three different levels of complexity. Starting from the deterministic perspective, fully contained in the algebraic domain, where no statistic is involved. Moving towards the decision analysis theory where part of the imperfection of the real world, such as uncertainty and risk, are translated with the problem. Ending with the Multi-Criteria Decision-Making where is no more the problem translated in the mathematical domain, instead are the mathematic techniques translated to be applied in the real domain.

Also even though a manager will almost never be the one that has to work directly with these instruments a general knowledge in this direction can be useful for two main reason, it gives to the manager more tools to work with in a problem-solving process, but more importantly it gives a totally different mindset under which it is possible to analyze a problem.

In the third chapter the discussion is shifted towards the concept of decision-making located in a managerial context from the human being perspective. Here, the entire problem-solving process is deeply discussed, defragmented and analyzed with greater emphasis to the concept of failure and its possible effects on the decision-maker.

Subsequently the discussion has shifted towards the team dynamics where different styles, behaviors, and interactions between team members can leads to unpredictable, sometimes suboptimal, decisions and results.

Lastly, the subjective assessment topic and its implications in the forecasting activity are discussed. With this last topic it was possible to close the circle about the main areas of influence of the human irrationality in the decision process.

In the fourth chapter the attention is shifted on the different data and information collecting instruments at disposal to the controller, starting with defining the huge importance of qualitative dimension of data over the quantitative one.

Regarding the data and information instruments the discussion has been divided in three different temporal bands: present, future, and past. As regards the feedforward control instruments the discussion stared with the data collection methods able to satisfy the demand for information in planning the current activities, such as full costing and more importantly Activity-Based Costing. Proceeding with the discussion of short-term and long-term decision-making instruments such as Cost Volume Profit analysis and Net Present Value respectively. Concluding with the important discussion about the role of standard, estimates and budgeting process in the firm's lifecycle. Moving towards the feedback control instruments the discussion stationed on the fundamental topic of performance measurement. Here has been discussed the distinction between monetary and non-monetary measures with a greater attention on the importance of correct and calibrated non-monetary ones.

Lastly the discussion has been shifted on the analysis of the perspective originated with a value-based approach to decisions.

In conclusion this thesis has given an almost complete vision of the decision-making process, covering all its fundamental perspectives, giving a complete representation of the environment, protagonists, instruments, and also the problem-solving process itself that can surround the manager in a scenario where it has to make a decision, be it the most banal one or the most important of all.

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