Quality in Design and Execution of Engineering Practice

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Foreword

The quality your customers really need inevitably differs from the quality as prescribed in specifications, rules and regulations. The author's message is, in short, to be aware of this fact in all quality related issues.

Quality as required by fitness for purpose can be in conflict with quality according to prevailing specifications, rules and regulations. It is then in the interest of the buyer to agree with the supplier on desirable exemptions. But often we can see that the supplier chooses the easy way out of just complying with the contract specifications without caring too much about the particular interests of the customer.

In the Damen Shipyards Group, we try to induce a corporate culture of always paying attention to the interests of our customers and making serious efforts to serve those interests, also when there is no contractual obligation to do so. This book constitutes a welcome means to spread this word throughout the entire organisation. I wholeheartedly recommend it to whoever wishes to be a genuine quality supplier.

Kommer Damen
Chairman of Damen Shipyards Group

Acknowledgements

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- Jonathan Barzilai provided the description of the Tetra software for multicriteria decision making of Section 6.1.
- Ruud Binnekamp produced the cases of Chapter 8.
- Our students delivered material for the following sections: Jan Sneekes the example of Section 6.3, *An application of preference measurement in the construction industry*; Axel Booij, Nienke Groenewegen, and Bram Kool the case for Section 8.3, *The Øresund Link*.
- Jeroen Burger took care of the editing.

Contents

1 Introduction

The quality of an engineering artefact is determined by:

1. Its design, defined by drawings and specifications,
2. The execution of the design.

In the first decade of my career, I was intensively involved in both the design and the manufacture of marine propellers, first as an industrial scientist and later being responsible for both the design department and the quality control department of the company. This enabled me to develop insights into the relation between the two and to conceive a quality classification that provides guidance in all kinds of quality related issues.

After publishing the classification in 1985, I received a letter from the highest executive responsible for quality assurance of an aircraft manufacturer, stating: "I now understand what I have been doing all those years."

The construction director of a US$ 4.3 billion construction project in China, told me how he had been able to save hundreds of millions of dollars by just rigorously applying the lessons that can be derived from the classification (see Chapter 7).

The strategic classification – License Giver, License Taker, Jobber, and Consultant – published in Long Range Planning (Van Gunsteren, 1987) and reproduced here as Appendix I, can be combined with the quality classification yielding useful guidance in how companies can exploit technology (Van Gunsteren, 2003a). For instance, quality of design is crucial for a License Giver, whereas quality of execution is of primary importance for a License Taker. In my consultancy, I have frequently used both models to explain my recommendations related to technological innovation.

In architecture, the trade-off functionality versus architectural beauty is always a subject of debate. Also in this domain, the quality classification proves to be useful, in particular when combined with preference measurement of stakeholders (Binnekamp, 2010).

Apparently, the quality classification provides useful guidance in various fields of engineering practice.

The mainstream of literature on quality, as becomes apparent from the publications of quality gurus like Deming, Juran and Crosby (see for instance Deming (1982); Juran and De Freo (2010); and Crosby (2000)), is focused on getting manufacturing execution in line with design. The design itself, as defined by drawings and specifications, is implicitly taken for granted. In mass production of cars and many other products, carried out by essentially License Takers, this assumption is justified. Indeed, for License Taker business units quality of execution is what matters most to remain competitive. But for a License Giver quality of design is crucial, and for a Jobber or Consultant it is quality as perceived by their customers.

My quality classification does not take design for granted. It recognizes the fact that design specifications and execution can never exactly cover all relevant quality as required by fitness for purpose. As a corollary, design and execution should always both be taken into consideration in quality-related engineering problems. In failures of engineering artefacts, the first attention is usually paid to execution and specifically to the question if specifications, rules and regulations* were properly met. Design aspects, by contrast, tend to be considered only in secondary instance and then, more often than not, turn out to be the cause of failure.

Of course, meeting specifications, rules and regulations, as emphasized in the mainstream of literature on quality management, is important in engineering practice. But there is more to it, as I hope to make clear is this volume: design and execution should be given equal weight in engineering practice.

My views on quality management have been shaped by inductive thinking – that is: observing special cases in practice and carefully drawing conclusions from them which might be generalized –, as opposed to deductive thinking – that is: assuming general truths to be valid for special cases – (Van Gunsteren, 2003b). Consequently, my views concern a mindset rather than a recipe for dealing with quality issues in engineering practice.

*Throughout this work, we use the term *rules and regulations* to refer to the *regulating framework* of a product, which consists of all relevant regulation, national and international legislation, technical codes and standards and rules for controlling and certifying the product (Van Gorp, 2005).

2 Classification of seven categories of quality

What is quality?

> Doing or making something well according to the norms of an evaluator or end user.

These norms depend on the purpose one has in mind, hence the definition:

> *Quality is fitness for purpose.*[*]

That means quality is:

1. Related to a subjective purpose.

2. A perception.

Absolute standards of quality do not exist. What quality is depends on the needs of the user. These needs are not only determined by the user's personal desires and preferences, but whenever new technologies offer new possibilities, the wishes of users will also become more demanding.

If we wish to get something done from a larger group of people, we have to resort to regulation: laws for a country; rules and standards for a trade; rules, procedures and policies for a corporation. Therefore:

> *Quality is not only a matter of knowledge and mentality, but equally of a proper definition of adequate quality specifications.*

Quality specifications – i.e. norms enabling the measurement of performance in doing or making – depend on:

1. *Purpose* of the end user (clean office, car that does not break down, etc.).

2. Experience in the past as far as *user problems* are concerned (breakdown, wear and tear, etc.).

3. *What can be measured?* For instance, environmental rules should not be so strict that violation cannot be measured.

[*] In the third edition of Juran's Quality Handbook, he defined Quality as *fitness for use*. In the sixth edition, he settled on: Quality means *fitness for purpose* (Juran and De Freo, 2010, p. 11). This definition had already been introduced in my earlier publications (Van Gunsteren, 1985, 2003a).

Quality can be:

1. *Relevant* or irrelevant for fitness for purpose.
2. *Realized* or not realized in the product or service.
3. *Specified* or not included in specifications.

Combinations of these aspects yield seven categories of quality which we will now discuss.

Quality specifications will never cover exactly all quality which is relevant to the end user (Figure 2.1). Relevant quality which is covered by specifications is labeled *crucial quality*, because it is absolutely crucial to realize this type of quality in the product or service. In the case of non-compliance, a claim would be justified both formally and because the user really needs that quality for his purpose. Relevant quality which is not specified is called *service quality*, because this quality has to be delivered as a service if the end user's needs are to be properly satisfied. Specified quality that does not serve any purpose of the end user is labeled *cosmetic quality*. Cosmetic quality consists of:

1. *Ritual quality*: realized cosmetic quality, and
2. *Excuse quality*: non-realized cosmetic quality.

Specifications (related to rules and regulations) are sometimes used as an excuse to exclude a supplier. For instance, the dimensions of car number plates in a certain country were prescribed in such a way that foreign suppliers were handicapped. In another country, an old-fashioned, inaccurate method to measure the dimensions of marine propellers (using templates) was prescribed to protect the backward domestic industry against more advanced international competitors.

Cosmetic quality should not be confused with cosmetic measures to give the product an attractive appearance, such as good looking packaging. This kind of cosmetics belongs to service quality, as it satisfies a real user's need.

Quality realized in the product or service will never cover exactly what is relevant and/or specified. Realized quality which is neither relevant nor specified is labeled *wasted quality*, as it serves no true purpose. Wasted quality is nihil in the engineer's ideal of Caesar's war chariot, which never fails but at the end of its lifetime disintegrates completely into dust. If one bolt were to remain, then that bolt would have been constructed too conservatively and that would have had adverse weight implications. Unnecessary weight impairs the effectiveness of the chariot, which Caesar would never have accepted. This completes our classification of the seven categories of quality (Figure 2.2).

The classification enables us to formulate some recommendations to both the supplier and the buyer or user (Tables 2.1, 2.2).

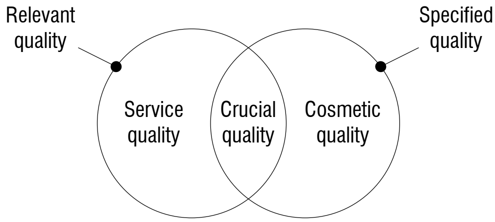


Figure 2.1 Quality specifications never cover exactly all relevant quality.

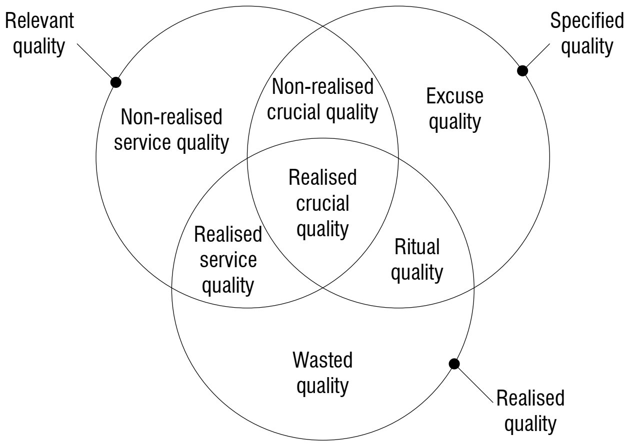


Figure 2.2 Classification of seven categories of quality.

Table 2.1 Recommendations on quality for the supplier

Quality improvement should be focused on the following categories:

Category	Problem (if too high)
Non-realized crucial quality	Short term; one can rightly be blamed for not complying with the specifications
Non-realized service quality	Long term; image will be established as not being a quality supplier
Wasted quality	Long term; results in unnecessarily high cost price; image will be established as being an expensive supplier
Excuse quality	Waste of resources: • Useless to try to comply with; a new stick to hit with can always be found. • Focus actions on the real reason of exclusion; in case of protectionism try to obtain a local face.

Example 1: *Rules for truck manufacture*

After complying with the strict rules in regard to the dimensions of number plates in a certain country, a foreign truck manufacturer was faced with a new procedure for measuring the width of their trucks. The result was that their trucks exceeded the allowed maximum by 5 centimeters. When that issue was resolved by political pressure, a new law related to noise emission was issued, with the effect that his trucks were no longer allowed to drive in that country during specific night hours; the local manufacturer's trucks were just within the norm. This process was finally terminated by political pressure, such as threatening to ban the competitor's trucks from the roads of the home country by using similar (excuse) quality rules.

Example 2: *Rules for marine propeller manufacture*

After inspection of a finished marine propeller for a fast container vessel it turned out that it was somewhat out of tolerance at the inner sections. This does not impair its 'fitness for use' to any extent, since the margins against cavitation are more than enough for those sections and the strength is also hardly affected. At the outer sections, however, where the dimensions were within the specified tolerances, a higher dimensional accuracy would favorably influence the likelihood of cavitation erosion.

The manufacturer offered to finish the propeller according to this higher standard at the outer sections, rather than to that required by the agreed specifications. In exchange, the manufacturer asked for acceptance of the existing dimensions of the inner sections. This was accepted by the customer. Through the exchange of some cosmetic quality (inner sections) for some service quality (outer sections), the end user obtained a better quality for his purpose and the manufacturer could avoid a costly rejection of the propeller.

As mentioned before, the mainstream of literature on quality is focused on getting execution in line with design specifications, rules and regulations (Figure 2.3). The author's approach, by contrast, is focused on getting execution in line with quality aspects as required by fitness for purpose (Figure 2.4).

Table 2.2 Recommendations on quality for the buyer (user)

• Be flexible with regard to cosmetic quality and pay more attention to service quality. • Exchanging some cosmetic quality for a little more service quality is often to the advantage of both the buyer and the supplier; this can be effected formally, i.e. via extra specifications, or informally in the acceptance procedure.

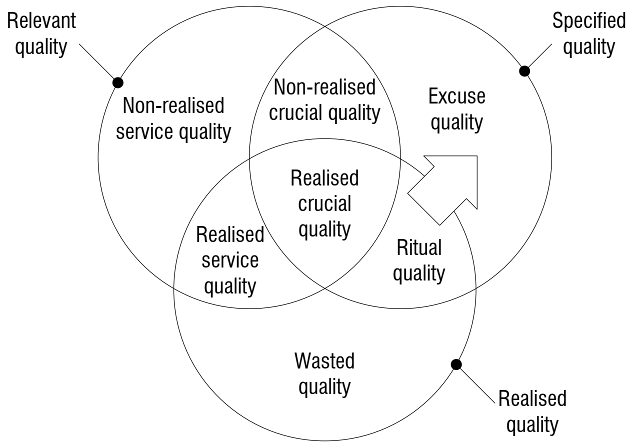


Figure 2.3 Emphasis of quality control and assurance according to the mainstream of literature: getting execution in line with design specifications.

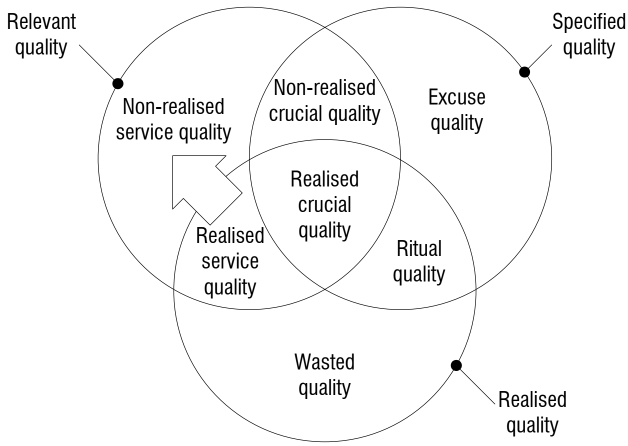


Figure 2.4 Author's approach of quality control and assurance: getting execution in line with fitness for purpose.

3 A typology of rules and regulations

3.1 An opinion poll on quality rules and regulations

An opinion poll among some 300 participants of a conference on quality assurance (Amsterdam, May 8, 1985) yielded the result shown in Figure 3.1 (Van Gunsteren, 1985). Even among experts, opinions on quality rules and regulations appear to vary widely. Let us address this issue with our classification of seven categories of quality.

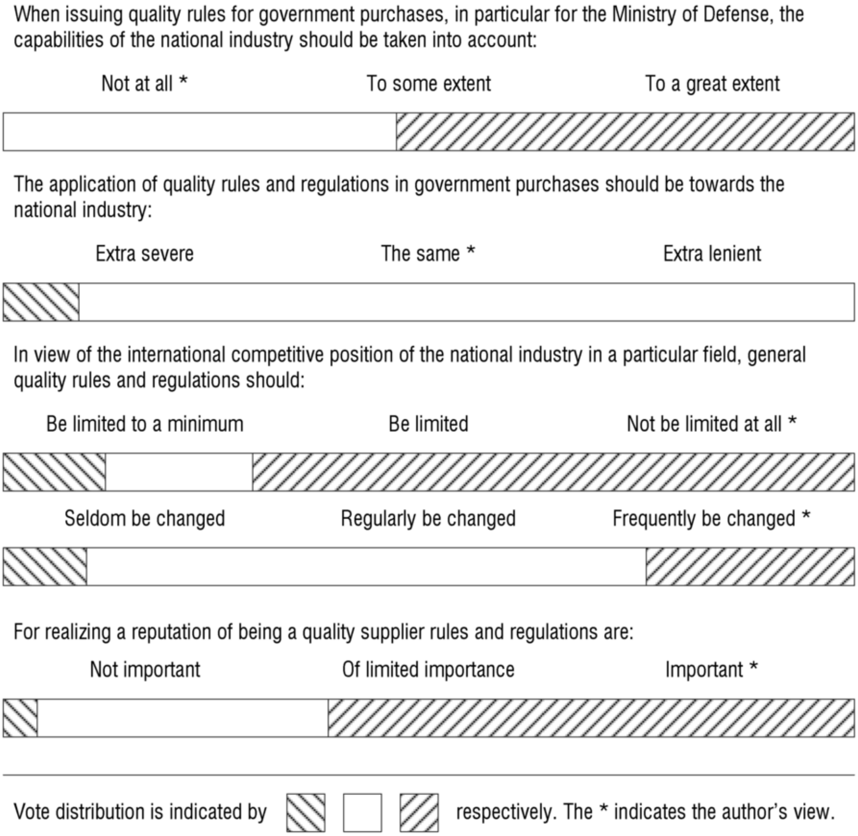


Figure 3.1 Poll reveals varying opinions on quality rules and regulations.

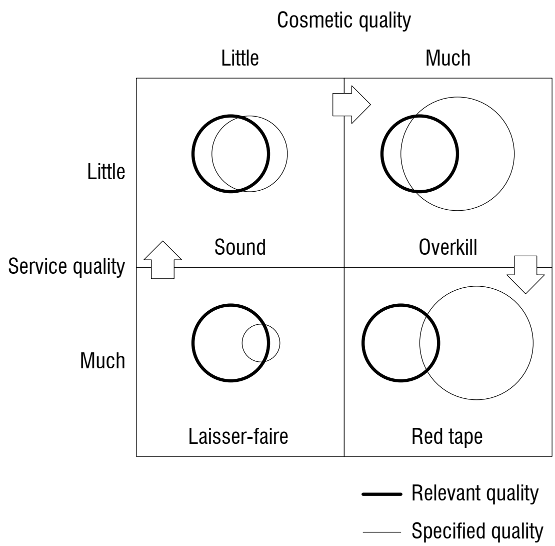


Figure 3.2 Typology of quality rules and regulations.

3.2 A typology of rules and regulations

Quality rules and regulations should be evaluated on the basis of their content of cosmetic quality and service quality, or:

1. How much is prescribed which is not really necessary?
2. How much is actually needed but not prescribed in rules and regulations?

A typology of quality rules and regulations, which is based on these two questions, is given in Figure 3.2. Four types of quality rules and regulations can be distinguished:

1. *Sound* quality rules and regulations cover mainly what is really needed (little cosmetic and service quality). Consequences: the desirable status.
2. *Overkill* quality rules and regulations cover much more than the real needs of the user (much cosmetic quality). Consequences:
    - Within the area where the rules and regulations hold, the local industry may have a short term advantage.
    - Prescribing aspects that are actually superfluous has an increasing effect upon cost prices, which impairs (international) competitive strength in the long term.

3. *Laisser-faire* quality rules and regulations cover the real needs of the user to a limited extent only (much service quality). Consequences:
    - On many occasions the reliable supplier loses to a competitor who complies with the rules and regulations but does not deliver what the user really needs.
    - As a result the supplier is compelled to opportunism and to decrease his quality; ultimately this reduces (international) competitive strength.
4. *Red tape* quality rules and regulations require a lot of superfluous things without covering what the user really needs (much cosmetic and service quality). Consequences:
    - Possible short-term advantages for the local industry.
    - Long-term results disastrous:
        (a) Much service quality makes it difficult to be profiled as a quality supplier.
        (b) Much cosmetic quality results in a high cost price and ultimately in an image of being an expensive supplier.

When a new technology emerges, there will be few generally accepted quality rules and regulations, i.e. a laisser-faire situation. In a mature industry, we can often observe an overkill situation. A red tape situation emerges when user needs and technical possibilities to satisfy them have shifted over time without commensurate changes in the rules and regulations. To maintain sound practices and fair competition in a trade, quality rules and regulations should evolve with changing user needs and technological innovations to satisfy them. This is primarily a responsibility of the market leader(s) within the industry. The pace at which change in quality rules and regulations should be effected depends on the pace at which new technologies are introduced. In certain periods of rapid technological progress, changes in rules and regulations may be needed quite frequently. In that case, frequent updating of quality rules and regulations is perfectly in order.

The arrows in Figure 3.2 indicate the development when new technology emerges from a Laisser-faire situation at the beginning to ultimately a Red tape situation. For instance, the offshore industry, when it emerged in the sixties, started with hardly any rules and regulations. In the next decades, lessons from accidents were incorporated in ever more and stricter rules and regulations until, via stages of Sound and Overkill, the Red tape situation of today was reached.

A similar development can be noticed in many other industries like cars, airplanes and buildings. This is natural. Every accident or disaster evokes demands for more and stricter rules and regulations.

Example 1: *Double bottom of oil tankers*

After some serious oil spill accidents, the rule was established that oil tankers should have a double bottom, although it hardly affects the probability of an oil spill. In the case of a collision, running aground or hitting an iceberg, a double bottom is of little help to prevent an oil spill. Modern navigation devices with automatic warning signals to avoid collisions all together are far more effective than a double bottom.

Example 2: *Safety measures in automobiles*

Like in the previous example, the safety measures in automobiles were initially aimed at alleviating the negative consequences of a crash by means of seatbelts and airbags. The current trend is towards avoiding collisions altogether by means of warning signals and associated devices which automatically slow down the vehicle whenever an obstacle like a traffic jam is approached. Once these systems prove to be effective, they will undoubtedly be followed by legislation that prescribes them to everybody.

3.3 Usefulness of rules and regulations

Let me describe some relevant experiences.

Experience 1: *Student memories*

Ship design was an important subject of my study of Naval Architecture in the early sixties at Delft University of Technology. In one of the lectures, the professor of ship design showed the design of the short-sea passenger vessels, known as canal boats, in which design he had been involved before becoming a university professor. To my surprise, the number of available seats in the lifeboats was far less than the number of passengers and crew on board. How could that be in agreement with the rules that had internationally been agreed after the sinking of the Titanic in 1912 (SOLAS: International Convention for the Safety of Life at Sea)? The Titanic could accommodate almost three times more passengers and crew on board than there were seats available in the lifeboats. The professor responded to my question saying that an exemption had been made for ships that stayed within a certain distance from the shore. To install more lifeboats would severely limit the passenger capacity of the ships. I was puzzled. Would shipwrecked individuals be able to swim that distance without drowning or dying from hypothermia? That seemed to be very unlikely to me.

Still intrigued by the subject when I was a member of the Naval Architecture student committee, I organised a two-day symposium on safety at sea on the occasion that the Titanic had gone down half a century earlier, on the 15th of April 1912. The symposium, of which the report is available in the Maritime Museum in Amsterdam, took place on April 12-13, 1962.

The famous inventor of life saving equipment, Mr A.P. Schat, was a keynote speaker. His lecture was unforgettable. Schat first described the event that had made him decide to devote his life to improving the safety at sea. As a young deckhand on board of a freighter, he had taken a profound dislike to both the captain and the other crewmembers. When he saw another vessel passing by he decided to change ships. He jumped overboard expecting the other ship to pick him up. To his horror, however, the people on the passing ship did not see him. So he found himself in the water with only a life jacket and no land in sight. Schat realised that only a miracle could save him. A miracle indeed occurred. A nearby warship happened to be engaged in an exercise that included looking for floating mines. Officers on the bridge with powerful night-glasses were intensively searching for floating objects. They spotted the swimmer and picked him up. Schat was saved. The event had made him painfully aware of the agony of shipwrecked persons when they are dependent on others to be saved. He saw his astonishing rescue as a sign from the Lord that he had to devote his life to the safety at sea.

Schat then continued his lecture describing his inventions: davits and gliding skates for the launching of lifeboats and in particular his invention of the totally enclosed lifeboat. The latter was initially not allowed since rules and regulations prescribed lifeboats to be open, presumably to make rowing possible and to make it easier for swimmers to get on board, but ignoring the fact that hypothermia is the most dangerous threat for shipwrecked people. The lecture would forever remain engrained in my memory, especially its conclusion that rules and regulations are sometimes a roadblock to progress rather than an asset.

Experience 2: *Company specific norms versus general rules and regulations*

In the early seventies, I was a member and the spokesman of the European marine propeller manufacturers in the international committees responsible for the rules and regulations in the trade: the ISO TC8 (nowadays R484) and Lloyd's Panel for Ship Propellers.

Our own company-specific norms for admissible stresses in propeller blades were, at that time, considerably stricter than the general rules and regulations. As a result, our track record of broken propellers, including our Joint Ventures worldwide that had their propeller designs made by us, was only one quarter of the world average according to the statistics of Lloyd's. Our design methods were a lot more sophisticated than the rather primitive rules of thumb in the general rules and regulations. If these general rules would be made stricter, we could encounter situations in which our company-specific norms would no longer be decisive for the blade thickness, but the rules and regulations. In such cases, we would have to make our propellers unnecessary heavy. In terms of our quality classification: the rules and regulations would prescribe the inclusion of substantial *cosmetic quality* in our product. I felt this to be a step backward and the opposite of technological progress. I therefore saw it as my role in the committees to prevent that stricter rules and regulations would create an *overkill* situation.

Our company specific norms included complicated aspects like the irregularity of the ship's wake field and the margins against cavitation. Since their analysis required powerful computers that small firms could not afford, it would be out of the question to include these aspects in the general rules and regulations. The usual approach to resolve this issue is to apply larger safety factors. This not only brings along substantial cosmetic quality, but is also by no means a guarantee against failure, as becomes apparent in our next experience.

Experience 3: *Failure of the slotted nozzle*

As described in Section 5.3, the first sizeable slotted nozzle, with an inside diameter of 5.2 meters, broke down after six months of service. Later analysis revealed that the discontinuity at the very stiff head box and the natural frequency of the nozzle being close to the blade frequency of the propeller had been responsible for the failure. The manufacturer of the nozzle to whom the construction design had been entrusted for commercial reasons, Kort Propulsion Ltd., had not made any analysis of fatigue stresses nor of vibrations. As a result, the nozzle broke down, although its design complied with ample margin with Lloyd's Rules and had been approved by Lloyd's.

These experiences show:

1. Complying with rules and regulations is by no means a guarantee against failure. It is an illusion to assume that it is.

2. Rules and regulations that are so strict that most failures are indeed prevented inevitably bring along substantial *cosmetic quality*.

3. Rules and regulations can be a serious roadblock to technological innovation.

In short, the usefulness of rules and regulations is limited. They generate unwarranted feelings of safety, lead to a waste of raw materials, and discourage innovation. But they are a reality of life, because every disaster evokes a demand from the public for more and stricter rules and regulations.

4 Quality and the business unit's identity

Strategic quality, i.e. relevant quality in the sense that it can provide a strategic advantage over the competition, depends on the business unit's identity: License Giver, License Taker, Jobber, and Consultant (Van Gunsteren, 2003a, reproduced in Appendix I). The implications with regard to quality for these four categories are as follows:

4.1 License Giver

- Relevant quality:
  1. What is desirable is determined by the (latent) needs of the users.
  2. What is achievable is determined by the available technologies.
- The design, translated into specifications, should cover relevant quality as much as possible (Figure 4.1).

Changing technologies make it possible to satisfy new latent wishes of end users. As a result, the License Giver's aim of taking care of sound design specifications implies a dynamic process.

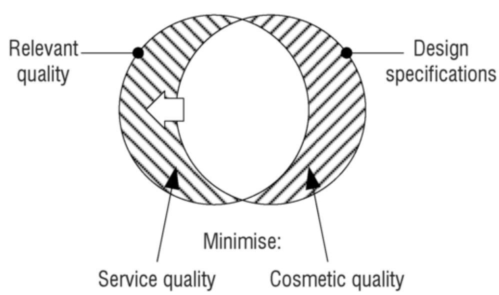


Figure 4.1 License Giver strategic quality aim: Taking care of sound design specifications.

4.2 License Taker

- Relevant quality:
    1. Primarily determined by the design and specifications of the License Giver.
    2. Secondarily determined by the special wishes of the customer.
- The product should, in the first place, comply with the design and the specifications, which are the License Giver's responsibility, as much as possible; service quality plays a subordinated role (Figure 4.2).
- In some instances a special customer's requirements are satisfied by exchanging some service quality for some cosmetic quality; service quality involving customer engineering should be limited to specific local market requirements (e.g. big bumpers on the Volkswagen Beetle when it was introduced in the U.S. market).

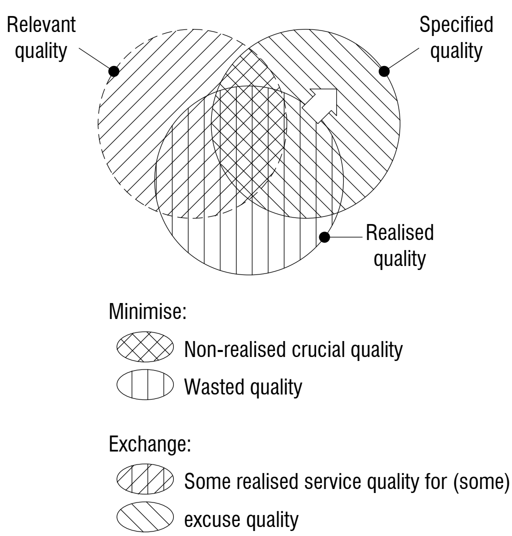


Figure 4.2 License Taker strategic quality aim: Taking care that the delivered product meets the specifications.

4.3 Jobber

- Relevant quality:
  1. Primarily determined by the perception of the customer.
  2. Secondarily determined by specifications.
- The delivered service must satisfy the subjective requirements of the customer as precisely as possible – no more, no less – (Figure 4.3).

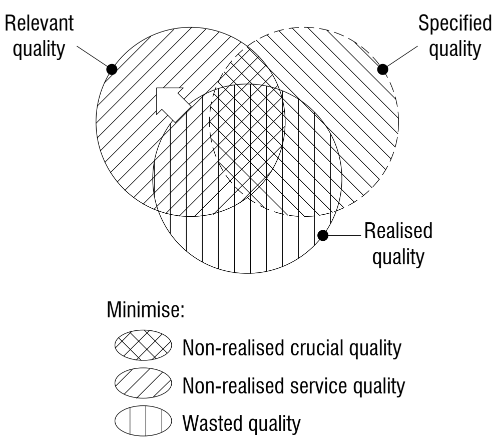


Figure 4.3 Jobber's strategic quality aim: Realising the subjective wishes of the customer.

4.4 Consultant

- Relevant quality:
  1. Primarily determined by the problem definition.
  2. Secondarily determined by imponderabilities as perceived by the customer.
- Delivered service (advice, information, design) should comply with the (real) problem definition as closely as possible (Figure 4.4).

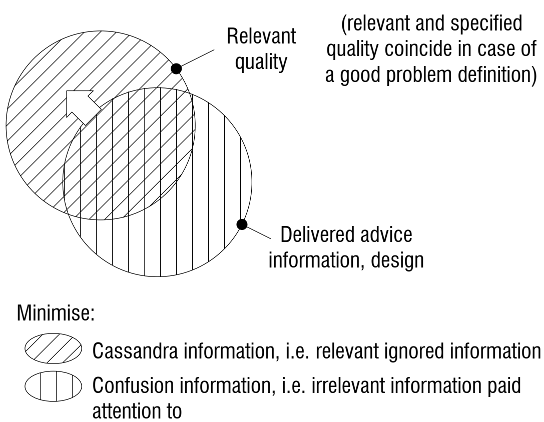


Figure 4.4 Consultant's strategic quality aim: Delivering exactly that knowledge which is relevant for the customer's specific problem. (See Appendix II: Information handling.)

5 Engineering design quality

5.1 What is a good engineering design?

To answer this question, let us look at some designs in the history of mankind, which have earned a reputation of being excellent designs in the era they were conceived. Some that immediately spring to mind are the following:

Ships

- The *Viking ships* enabled the Vikings to discover America a long time before Columbus.
- The *VOC ships* could be built so quickly that the VOC could grow to become the largest corporation in the world.
- The *Liberty ship*, which housewives could build at a rate of one per day. The German submarines could never sink them at such a fast rate.

Aircraft

- *Boeing 747 jumbo jet.* Nothing special but exactly the increase in size required by the market at the time.
- *Spitfire.* When Goering asked his air force general what he needed to win the war in the air, the answer was: 'Give me a squadron of Spitfires.'

Automobiles

- *2CV.* Low-cost car in which farmers could transport eggs without breaking them.
- *Porsche 911.* At the time, a breakthrough in sports car performance.

Constructions

- *Eiffel Tower.* An eye catcher for the world exhibition in Paris, which is even today a symbol for the whole city.
- *Golden Gate Bridge.* The symbol for San Francisco's progressive society.
- *Sydney Opera House.* Ideal acoustics in a building that became a symbol for the whole country.

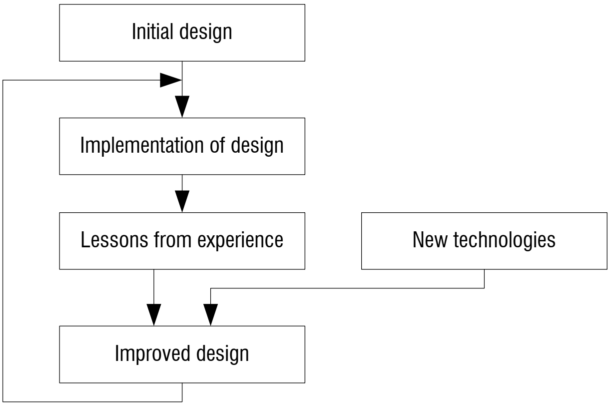


Figure 5.1 Lessons from experience and new technologies enable ever improving engineering design quality.

What do these and other brilliant designs have in common?

First, *fitness for purpose*. The design satisfies the requirements that follow from its mission exceptionally well.

Second, *technological balance*. Subsystems and components are in balance with each other: levels of reliability, sophistication, luxury, etc. are all in the same range. For instance, in warship design all subsystems should aim at the same level of shock resistance.

Third, *state-of-the-art technology*. Available technologies that can effectively be applied are indeed used. Appropriate, opportunistic use is made of state-of-the-art technology that has proven itself.

These three characteristics of a good design make designing largely a skill, which entails a way of thinking as well as knowledge of relevant technologies and methods.

5.2 The dynamic nature of engineering design

The third criterion of engineering design quality – exploiting state-of-the-art technology – implies a dynamic nature of engineering design. Spitfires would be of little value in today's warfare. The T-ford, which was revolutionary at the time, would look ridiculous in the car markets of 21st century. Nowadays, the quality of automobile design is highly influenced by the proper application of electronics and new materials which have become available in the last decades.

In addition to the incorporation of new technologies, lessons from experience lead to ever improving design quality (Figure 5.1). Every disaster –

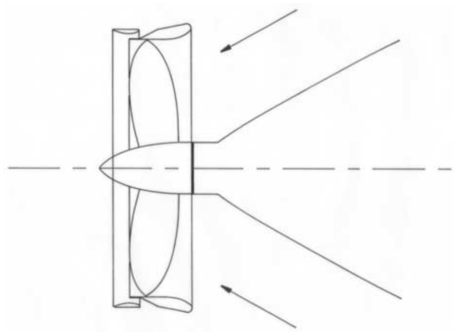


Figure 5.2 Wing nozzle

air crash, collapse of a building or bridge, collision of ships, etc. – generates valuable lessons from experience enabling designs and design methods to be improved. Failures are essential for progress. The design concept of the Twin Towers is forever abandoned after the 9-11-collapse in 2001. Lessons from aircraft crashes have led to ever improving safety of transport through the air.

Engineering design constitutes inevitably a compromise of conflicting requirements. Safety margins cannot be increased indefinitely without seriously impairing fitness for purpose.

The role of failure in engineering design has been convincingly been described by Henry Petroski (1992). I will limit myself here to adding some examples from my own practice.

5.3 Wing nozzle

A wing nozzle is a duct with a slot at the rear (Figure 5.2). The wing nozzle is nowadays a well-appreciated ship propulsion device, in particular for *double-duty ships* for which free running speed and bollard pull are both of importance. Examples:

1. Salvage tugs, which have to be fast to reach their target on time but once on location need to be able to generate a strong towing pull.

2. Fishing boats, which need speed to reach their fishing grounds but then require pulling power to tow their nets.

A second category of ships benefitting from a wing nozzle concerns vessels having not enough space in the aperture to fit a conventional nozzle with a chord-diameter ratio of 0.5. A wing nozzle has a chord-diameter ratio of 0.35. In this category, coasters with an open wheel can improve their propulsive

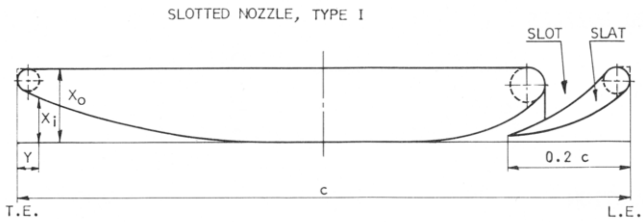


Figure 5.3 Profile of slotted nozzle (Van Gunsteren, 1973).

efficiency by fitting a wing nozzle, which also reduces the noise level in the aft ship.

The road that had to be travelled before the invention of the wing nozzle could prove itself in practice is typical for technological innovation. It took two failures before the market accepted the invention:

1. The failure of the slotted nozzle on two 14.3 MW (20,000 HP) salvage tugs, at that time the most powerful in the world. The slotted nozzle, having the slot at the front, is the predecessor of the wing nozzle, which has the slot at the rear.

2. The failure of the first sizable application of the wing nozzle on ships with extremely blunt lines in the aft body.

Both cases have extensively been described in my booklet *On Innovation* (Van Gunsteren, 2003a), so we can limit ourselves here to the role of these failures in improving the quality of nozzle designs.

Failure of the first sizable slotted nozzle

A slotted nozzle consists of an annular airfoil with a slot at the leading edge (Figure 5.3). The slot permits a pressure exchange between the pressure and suction side of the profile, lessening the risk of flow separation and making it possible to realize higher lift coefficients than can be obtained from non-slotted profiles. Slotted wing sections are therefore known in aerodynamics as 'high-lift devices'. See, for instance, Abott and von Doenhoff (1959).

Since a slot at the leading edge of a two-dimensional section can increase the maximum lift coefficient by approximately 50 percent, it is reasonable to suppose that the maximum lift coefficient of an annular airfoil (nozzle) could also be increased by the same means. This implies that the chord (length) of the nozzle can be reduced, or the camber and diffuser angle increased, without incurring a risk of flow separation.

The slotted nozzle was first proposed by the author in an attempt to improve the characteristics of ring propellers. A ring propeller is a propeller with a ring airfoil fitted to the blade tips, so that the ring rotates with the propeller. The patent of the slotted nozzle invention (British Patent Application No. 44019, 5 September 1969) covers both rotating and completely non-rotating slotted nozzles. The drawback of rotating configurations is the roughly 30 percent lower optimum rotational speed, causing higher gearing costs. The ring propeller is, for that reason, only of interest in practice when a non-rotating nozzle cannot be fitted to the hull.

The history of the first (sizable) slotted nozzle can be summarized as follows.

1973 Lips Propeller Works gets the order for two controllable pitch propeller installations with slotted nozzles, each of 14.3 MW, for the most powerful tugs in the world. The customer is SAFMarine Cape Town. The order went to Lips because only the slotted nozzle (with a chord-diameter ratio c/D=0.3) could make it possible to comply with both a required free running speed of 20 knots and a bollard pull of 180 tons.

1975 The author starts a lawsuit about the intellectual property rights of the slotted nozzle. Nine years later, the lawsuit would be decided in his favour: Lips had to pay him Dfl. 148,000 (nowadays about the same amount in dollars) and also transfer the patent rights, since Lips had argued in court that the slotted nozzle could never be made strong enough.

1976 Commissioning after a successful trial trip: bollard pull with ample margin above 180 tons, free running speed well over 20 knots, excellent steering characteristics and no vibrations. Then, however, the first of the two tugs, the 'Wolraad Woltemade', loses the port side of the nozzle after being in service for about six months. The second tug, the 'John Ross', in dry dock after her trial trip, shows cracks at the attachments of the nozzle to the heel and the head box (Figure 5.4).

The nozzles are then removed and the propeller blades are rounded off at the blade tips. The bollard pull without nozzle is thereby reduced from 185 tons to 135 tons.

1979 A conventional nozzle with a chord-diameter ratio c/D=0.45 is fitted. Comparison with the slotted nozzle:

- Propeller diameter 5.0 meters versus 5.2 meters for the slotted nozzle.
- Free running speed 0.4 knots lower than with the slotted nozzle.
- Bollardpull 10 tons more than with the slotted nozzle.

1987 The author starts the innovation company 'van Gunsteren & Gelling Marine Development BV' to exploit the patent rights of the slotted nozzle.

Figure 5.4 Cracks in slotted nozzle of 'John Ross' after trials

Analysis of the failure of the slotted nozzle on the South African tugs then reveals that the discontinuity of strength at the head box and the natural frequency of the nozzle being close to the blade frequency had been the cause of the failure. That fatigue strength and vibrations had not been properly accounted for was the result of the instruction from the commercial director of Lips to leave those matters to the manufacturer of the nozzles, Kort Propulsion Ltd., in order to have a claim on them if the nozzle would fail.

Failure of the first sizable wing nozzle

The author and his partner Jaap Gelling then conceived the idea of locating the slot at the trailing edge instead of at the leading edge of the profile. This concept, initially called a flapped nozzle, is nowadays known as *wing nozzle*. A wing nozzle has the same performance characteristics as a slotted nozzle, but offered two advantages:

1. Any cavitation from the slot would not come into the propeller disk.
2. A new patent could be obtained, providing protection for another twenty years.

Just like the slotted nozzle, the first sizable application of the wing nozzle (after some small nozzles for mussel boats) was a failure. The ship was vibrating heavily due to the blunt lines of the aft body, but the wing nozzle was blamed for it and was removed from the vessel. Fortunately, this was not a reason for Damen Shipyards to cancel their order for wing nozzles on a series of five coasters. At their trial trip, it soon became apparent that the wing nozzle performed as predicted and also reduced the noise level in the aft ship to below the legally allowed level. The innovation was saved and a step forward was made in marine propulsion after two failures that occurred due to circumstances having nothing to do with the invention itself.

5.4 Contra-rotating propeller design

The quality of an engineering design is not only determined by the skills and knowledge of the designer, but also by the quality of the design method that was used. To establish the quality of an engineering design method, the same criteria hold as for the artefact itself:

1. Fitness for purpose: generating designs that fit the purpose of the user.
2. Balance of design aspects, the same level of sophistication in all relevant design aspects: efficiency, strength, vibrations, corrosion, etc.
3. Proper application of available methods: mathematical models, empirical rules of the thumb, static and dynamic models, etc.

For instance, the failure of the slotted nozzle was caused by a lack of balance in design sophistication. Hydrodynamic aspects, efficiency as well as cavitation, were taken care of using the most sophisticated methods available: theory of high-lift airfoils, optimization of efficiency with series of systematic open water tests, and testing the design in the vacuum tank. Aspects of strength and vibrations were, for commercial reasons, left to the manufacturer of the nozzle who relied entirely on empirical rules of the thumb and did not make any analysis of fatigue strength and vibrations. In other words: too much empiricism and not enough, actually hardly any, mathematical analysis.

Mathematical models can never exactly reflect reality, making it necessary to introduce empirical correction factors. As a corollary, the quality of an engineering design method is highly affected by its mixture of mathematical sophistication and empiricism.

As an example, let me describe the experience related to my design method for contra-rotating propellers.

My basic idea was to use momentum theory to calculate the change in inflow velocities due to the interaction of the two propellers. With the resulting correction on the inflow velocities, the propellers could be designed with a computer programme for single propellers. This is the essence of my method. The Lips design programme had the reputation to be the best in the world. Over the years, operational feedback from over ten thousand propeller designs had been incorporated in the programme. Propellers designed with it could not only be expected to have the right pitch for optimal power absorption, but also to have close to optimal radial distributions of camber, chord length and thickness of the blade sections. The purpose of my approach was to use all this as well in the design of contra-rotating propellers, even if some concessions had to be made in regard to mathematical rigour.

My paper on the subject was submitted to the Journal of Ship Research, but the referee advised to reject the paper on exactly that ground. He pointed out that more sophisticated lifting surface methods were available. The essential feature of my method, that it enabled the design of the propellers to be made with a design programme for single propellers, was completely ignored in his comments. The paper was then accepted by International Shipbuilding Progress (Van Gunsteren, 1971).

Years later, proof became available that my method produces better contra-rotating propeller designs than the lifting surface methods that had been developed solely for contra-rotating propellers.

After Japan had commissioned two cargo ships with contra-rotating propellers (IHI and Mitsubishi), the US Maritime Administration feared that the US would lag behind in experience with this type of propulsion. A project was launched to equip a seagoing vessel with contra-rotating propellers, which would be manufactured by Lips Propeller Works. The question then arose who should design them: Lips or the US Navy's David Taylor Model Basin NSRDC (Naval Ship Research and Development Center) in Washington. It was decided that both would produce a design. Extensive model tests, on propulsion efficiency as well as cavitation, would be conducted for both designs. The results would be decisive for the choice of design.

The model tests proved that the Lips design was, with ample margin, superior to the American design, in efficiency as well as cavitation properties. The Lips engineer in charge of the matter had done nothing more than feeding the input data concerned into my design programme. He did not change anything in the output (shape of the propellers).

Why could the Lips design perform significantly better than the American design made with a sophisticated lifting surface theory dedicated exclusively to contra-rotating propellers? For the simple reason that my method allowed the use of a single propeller design procedure, in which an unprecedented amount of operational experience had been incorporated.

The example illustrates the importance of feedback from practice for the quality of engineering design. By the same token, one should be careful to transfer production to low-wages countries as many corporations do. When production facilities are located at the other side of the globe, such feedback can no longer be obtained in a natural way and, as a result, quality of design will suffer in the long run.

5.5 The multi-purpose pitfall

Quality is *fitness for purpose*. But what purpose? Sometimes the purpose is unclear or ambiguous because stakeholders cannot make up their mind and specify several, conflicting, purposes. They fall into the trap of what we may call the *multi-purpose pitfall*. When this happens, adequate engineering design becomes impossible.

> Example 1: *All-purpose extrusion press*
>
> A creative engineer invented an all-purpose extrusion press that could extrude all kinds of rods from copper or aluminium alloys: rods having a round profile, a square profile, a U-form profile, etc. To his surprise, however, the business he had started to exploit his invention went bankrupt. Why? When he was producing round profiled rods, he was more expensive than a competitor with a press dedicated to producing round rods only. When he was producing square profiled rods, he was more expensive than another competitor who could only produce square profiled rods. In short, he was always more expensive than the competition, making it impossible to turn his invention (new technical trick) into an innovation (something new a customer is prepared to pay for).

Multi-purpose design inevitably brings along *wasted quality* associated with the purposes that are momentarily not served. Once being aware of this, we can see it all around us, for instance in software becoming hopelessly user-unfriendly due to adding features that are relevant to only a few potential users.

The waste of money caused by the wasted quality of multi-purpose design can be enormous, as in our second example, the F-35-JSF (Joint Strike Fighter) aeroplane.

> Example 2: *The Joint Strike Fighter*
>
> The multi-national F-35-JFS program, the largest military program ever, according to current estimates costing the staggering amount of close to US$ 1 trillion, is a complete failure from an engineering design point of view. Why? Because the design does not reflect the overriding design constraint: *weight*. The weight of an aeroplane has to be carried by the lift of its wings. Likewise, the weight of a ship has to be equal to the weight of the displacement according to Archimedes' law.
>
> The JSF is supposed to fulfil three different missions:
>
> 1. Close-air support: assisting ground forces in their combat.

2. Air-to-air fighting, also called dogfight: combat with other fighter planes.
3. Long distance bombing.

Two of these missions, close-air support and air-to-air fighting, require a manoeuvrability that the JSF cannot deliver due to its unfavourable lift/weight ratio. When an object moves in a circle, it has a centripetal (inward) acceleration generating a centrifugal (outward) force, which is proportional to the radius of the circle and the object's velocity squared. This centrifugal force has to be counteracted by extra lift apart from the lift for carrying the weight of the aeroplane itself. Multiple purposes have multiple weight consequences, which are responsible for the unfavourable lift/weight ratio and consequently poor manoeuvrability of the JSF.

In addition to the three kinds of mission mentioned before, the JSF is supposed to serve the interests of four different groups of stakeholders:

1. The Air force, primarily interested in dogfight and bombing.
2. The Navy, interested in a version enabling take-off and landing on the short runway of an aircraft carrier.
3. The Marines, interested in the close-air support mission.
4. All those whose job security is at stake, both in the US and in the participating countries.

Combining these four different interests with the three kinds of mission yields twelve different purposes! A more striking example of falling into the trap of the multi-purpose pitfall is hardly imaginable. No wonder that the result is an aeroplane that was qualified in the presentation of the 2008-RAND-report as 'next to useless' since in visual range combat it 'can't turn, can't climb, can't run'.

Pierre M. Sprey, a key member of the A10 and F16 design teams, estimates that the maximum centripetal acceleration the JSF can achieve is a poor 2g (Sprey, 2012). Already in 2008 he pointed out: Even without new problems the F35 is a dog. It is overweight and underpowered. With a 49,000 lb take-off weight and an engine rated at 42,000 lb of thrust, it will be a significant step backward in thrust/weight ratio for a new fighter. The F35-A and F35-B variants will have a wing loading of 108 lb per square foot, making it less manoeuvrable than the appallingly vulnerable F-105 "Lead

Sled" that got wiped out over North Vietnam. Its payload is only two 2000 lb bombs. With more bombs the F-35 instantly becomes non-stealthy. As to close-air support it is too fast to see the tactical targets it is shooting at. It is too delicate and flammable to withstand ground fire. It lacks the payload and especially the endurance to loiter usefully over ground forces for sustained periods. A stealthy aircraft is quite detectable by radar; it is simply a question of the type of radar and its angle relative to the aircraft. As for the highly complex electronics to attack targets in the air, the F-35, like the F-22 before it, has mortgaged its success on a hypothetical vision of ultra-long range radar-based air-to-air combat that has fallen on its face many times in real air war.

Later Sprey added another relevant consideration to his arguments. The cost of the infrastructure to keep the aircraft operational will be so high that cost cutting will be pursued by reducing the hours in the air for training of pilots to as few as 10 hours, about one third of what was considered at the end of the Vietnam war to be the absolute minimum to complement training in simulators. War experience reveals that the pilot is vastly more important than the airplane. As Sprey puts it: a good pilot in a terrible airplane is far more valuable than a fabulous airplane with a poor pilot.

One may wonder why an extremely expensive program is continued for the development of an airplane that is 'next to useless' and not capable of fulfilling two of the three missions it is intended for.

I can see three reasons why the decision makers involved seem to be deaf to the warnings of seasoned design engineers:

1. The idea of an airplane that can fulfil all conceivable missions and serve the interests of all relevant stakeholders is extremely attractive, whilst it is not obvious to non-technical people that it is unattainable. It is like the perpetual mobile: highly desirable, but unattainable because of the laws of physics.
2. The notion of 'sunk cost' is hard to accept, especially for the people who initially approved the project. Experienced general managers of technology-based companies agree that to abandon a project in which considerable investments have been made, is one of their most difficult tasks. 'We have already spent so much' is, of course, no argument to throw good money after bad, but it nevertheless always seems to play a role. The money has gone and it is of no use to cry

about spilled milk. When it is already so difficult for business leaders to admit that their initial judgement was wrong, what can we expect from politicians?

3. Too many people have a personal interest in the continuation of the program. Lockheed Martin, the prime contractor of the program, is reported to have spent US$ 23 million in political campaigning, US$ 125 million on lobbying, and to have received US$ 20 million in earmarks. That is a lot of money to buy votes and support in addition to the support the program already enjoys from those whose jobs are at stake.

How can design engineers avoid falling into the trap of the multi-purpose pitfall? They have to make clear to their sponsors that what is demanded from them is simply impossible. Instead of making compromises between conflicting purposes, they must insist that decisions are made on completely removing some of the conflicting purposes. They must have the courage to convey this unpleasant message to their superiors as a code of their profession, like a physician who has to inform a patient diagnosed with a terminal disease.

When multi-criteria and various groups of stakeholders are involved in the choice of purpose(s), preference measurement, as described in Chapter 6, can be of great help.

5.6 Mathematical modelling in engineering design

Mathematical modelling constitutes an indispensable part of engineering design practice. To prevent the collapse of any engineering artefact, we make calculations of stresses and vibrations that are all based on mathematical modelling. The speed and capacity of today's computers enable strength calculations of arbitrarily shaped bodies to be made by means of finite element methods (dividing the structure into finite elements, applying the equilibrium and fitting conditions on those elements thereby yielding a set of linear equations that can be solved by the computer).

In our analysis of a design, we make simplifying assumptions:

1. In the mathematical modelling;
2. On the maximum static and dynamic loads to be expected;
3. On the maximum tensile and fatigue stresses the employed materials can withstand.

The simplifying assumptions make it possible to calculate the expected stresses in the structure of any design as a fraction of the maximum tensile or fatigue

Table 5.1 Primiteve versus sophisticated mathematical modelling

	Mathematical modelling	
	Primitive	Sophisticated
Safety factors	High	Low
Cosmetic quality content	Much	Little

stress as can be measured in the laboratory. We call the reciprocal of this fraction the *safety factor*.

The more sophisticated our mathematical modelling is, the lower the safety factors can be, and as a consequence, the lower the *cosmetic quality* content in the design (Table 5.1).

In aircraft and ship design, the overriding design constraint is *weight*. As a corollary, methods of analysis in aircraft design tend to be sophisticated allowing safety factors to be relatively low and cosmetic quality content to be rather limited.

In construction design, weight is usually not of importance. As a corollary, methods of analysis in construction design tend to be primitive, which necessitates safety factors to be high and cosmetic quality content to be substantial. Since buildings tend to be over-designed as compared to aircraft and ships, diminishing the cosmetic quality content in construction design by applying sophisticated methods from aircraft and ship design could yield enormous savings in raw materials and money.

6 Measuring fitness for purpose: preference measurement

An objective measurement of quality is not possible because quality is a perception, which is per definition subjective. As a corollary, we cannot measure quality directly, like we measure physical properties of objects.

We can, however, measure quality indirectly by measuring the preferences of individuals for different alternatives. For instance, the quality of a movie is measured by comparison with other movies and letting a jury decide which movie they prefer and should get an Oscar.

Likewise, scientific quality is measured by comparing the work of candidates for the Nobel Prize and granting the prize to the most preferred one.

Architectural quality is measured by letting a jury or committee choose from different designs offered by invited architects. Members of a jury may have different preferences. This raises the question how to measure, in a correct way, their preference as a group of individuals. Multi Criteria Decision Analysis (MCDA) offers a solution for this.

In this chapter, a software tool* is offered for this purpose, based on the theory of Preference Function Modeling (Barzilai, 2010).

6.1 Tetra software for multi-criteria decision-making

The purpose of this section is to give the reader an overview of the steps involved in using the Tetra decision making software to evaluate choices using preference function modeling. Tetra comes in two versions: One of which is used by a single decision maker (SDM). It is 'standalone,' in that everything is installed on a single computer, and all model information is stored in documents on that computer. The other is for group decision making (GDM). It is based on the use of a Tetra server, and all model information is stored on the server, allowing it to be accessed by users running Tetra on multiple workstations on a network. As the use of both versions is identical in many respects, this description covers both versions, pointing out the differences where appropriate.

You will see how to use Tetra to evaluate a number of alternatives, based on criteria organized in a hierarchical manner. The alternatives are rated on each of the criteria. In the case of SDM a single evaluator specifies his or her ratings. With GDM multiple decision makers can participate in the process.

*See http://www.scientificmetrics.com/ for more information and an evaluation version.

The process of using Tetra to make a decision consists of eight steps:

1. Create a model.
2. Define the Decision Makers who will be involved in the process (GDM only).
3. Define the alternatives to be considered in making the decision.
4. Define the criteria upon which the decision will be based. These criteria may be defined in a tree-like structure, using main criteria, sub-criteria, sub-sub-criteria, and so on.
5. Define the weights for all criteria. These are defined relatively, specifying how important each criterion is in relation to others. The weights are defined at each node of the criteria tree.
6. Establish reference alternatives for each criterion.
7. Each Decision Maker enters his or her ratings for each alternative with respect to each criterion.
8. 'Solve' the model that has been created by the previous steps to compute the overall scores and get a numerical rating of the alternatives that corresponds to the combined ratings of all of the Decision Makers.

6.2 Example: Buying a house

Step 1 – Creating and Opening a Model

In Tetra SDM, simply select New... under the File menu, or click on the New Model icon in the tool bar. You will be prompted to select a location to save the model file. Once you have done this, move on to Step 3.

In Tetra GDM, models are created on a server, and each client is set up for access to the server using the Tetra GDM Administration Tool. Information on creating models is contained in the online help for the Tetra GDM Administration Tool. Once a model has been created, and your computer is set up to access the Tetra server, you will need the following information to access the model:

- The server on which the model is located
- The name of the model
- Your personal username and password for the model
- The model password used by everyone accessing the model

Choose Open Model... under the File menu, and provide the necessary information. In Tetra GDM there is the option of opening the model in Exclusive Mode. This can only be done by the Model Owner, and allows viewing of all the Decision Maker ratings.

Step 2 – Defining Decision Makers (Tetra GDM Only)

In Tetra GDM the Model Owner specifies other users who can access the model. To do this, open the model as described above, and then choose Edit Decision Makers... under the File menu.

There are three different types of access that can be provided to models:

- Model Owner: This user is created in the process of creating the model using the Tetra GDM Administration Tool. The Model Owner is the only user who can define and modify the model. Like Decision Makers, the Model Owner can also specify ratings. The Model Owner is also responsible for defining the other users who have access to the model.
- Decision Maker: These users can view a model and specify their ratings for the alternatives based on the criteria defined. They cannot see weights or the ratings of other Decision Makers.
- Read Only: This type of user can only view the alternatives and criteria of the model, and cannot make any changes, specify or view any weights, or specify ratings. If this user was a Decision Maker at some time in the past, and specified ratings then, these ratings would still be visible to the user, but they would not be editable.

There are two primary uses of Read Only users. The simplest is when you want to have a user who can view the alternatives and criteria, but who will not be providing ratings for the decision making process. In this case, be sure to set the weight of the user to zero. Another use for Read Only users is to 'freeze' the ratings of a Decision Maker. To do this, the Model Owner can choose Edit Decision Makers... under the File menu, select the desired Decision Maker, and then change the type of a Decision Maker user to Read Only. In this case you should leave the weight of the user as is, and not change it to zero, as doing so would remove that user's ratings from the computation of the model solution.

You should work through this procedure initially as the Model Owner, with no additional Decision Makers defined. Once you have completed this guide, create at least one Decision Maker, and one Read Only user, then close the model and reopen it as each of these users to explore the differences in access privileges. Once the model has been defined, if you are accessing the model as a Decision Maker skip to Step 7. If you are a Read Only user, you can simply browse the model, using the on-line help if necessary.

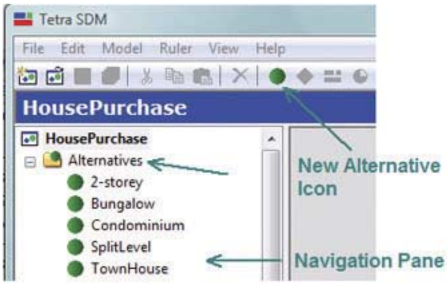


Figure 6.1 Creating alternatives.

Step 3 – Identify Alternatives

Remember that, in Tetra GDM, you must be the Model Owner, and have the model opened in exclusive mode, in order to perform this step.

Suppose you have narrowed the choice to 5 acceptable homes: a bungalow, a split-level, a 2-storey house, a townhouse and a condominium.

Tetra actions to create alternatives (Figure 6.1):

- Right-click on the word Alternatives in the Navigation Pane and Select New Alternative (or click on the New Alternative icon in the toolbar) once for each of your five alternatives, and name the five houses accordingly.

Step 4 – Define Criteria

Remember that, in Tetra GDM, you must be the Model Owner, and have the model opened in exclusive mode, in order to perform this step.

Assume that house Size, Cost, Quality and Location are your main criteria for making the decision. Furthermore, assume that your preference for the location actually depends on two sub-criteria: Distance to Work, and Distance to School for the children. Also, with respect to cost, you realize that you are concerned with the Taxes as well as the purchase Price (two more sub-criteria). The evaluation criteria are shown in Figure 6.2.

The method requires that you only state your ratings for the last level of sub-criteria on any branch, in this case the six bolded criteria.

Tetra actions to create criteria (Figure 6.3):

- Right click on the word Criteria in the criteria tree and select New Criterion (or click on the new criterion icon in the toolbar) once for each of your four main criteria, and name them accordingly.

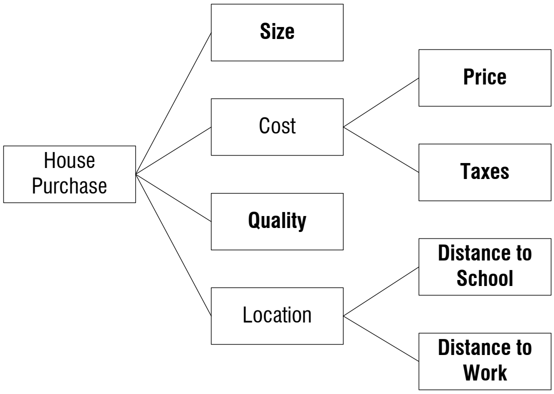


Figure 6.2 Defining criteria.

Tetra actions to create sub-criteria:

- Select a criterion (such as Cost) in the criteria tree for which you want to enter sub-criteria, and now when you right click on it and select New Criterion (or click on the new criterion icon) new branches are created under the selected criterion. Observe that, when you define a sub-criteria, the icon of the criterion you create it below is changed from a simple criterion icon to a criteria folder icon.
- Repeat this process for all sub-criteria. Create price and taxes sub-criteria for the cost part of the hierarchy, and create distance to school and distance to work sub-criteria for the location part of the hierarchy.

Step 5 – Assign Weights to the Criteria

Remember that, in Tetra GDM, you must be the Model Owner, and have the model opened in exclusive mode, in order to perform this step.

Defining the weights establishes the relative importance of the various criteria involved in making the decision. Weights are assigned using the same hierarchy as the criteria tree.

Tetra actions to create a set of weights (Figure 6.4):

- Right click on the word Weights in the model tree, immediately below the top-level criteria folder and Select New Weighting Ruler, or select the word Weights under the top-level criteria folder and click on the New Weighting Ruler icon in the toolbar. You may give the set of weights a name if you like.

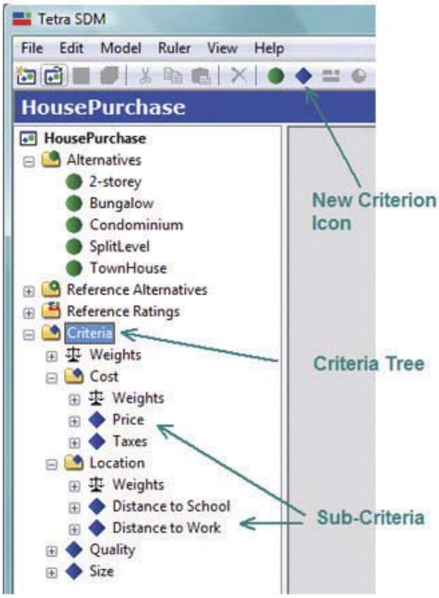


Figure 6.3 Creating criteria.

- Double-click on the label for the current set of weights in the criteria tree ('Buyer 1' in this case). A blank weighting ruler will appear in the ruler area.
- Right click anywhere in the ruler area, select Add Criterion, then Add All. The resulting figure is shown below.
- The weights are relative, so the method works by setting one criterion as a 'standard' against which the importance of another one is specified. Tetra initially sets one arbitrary criterion as the reference weight (Size in the figure), with a magnitude indicated by the red bar. The blue bar is associated with one other criterion weight (Quality in the figure). The length of the blue bar relative to the red bar, quantified by the boxed percentage between the rulers in the figure, corresponds to the relative importance of these two criteria (i.e. Quality is 80% as important as Size in the default set-up shown below).

Tetra actions to assign the weights for the top-level criteria (Figure 6.5):

- Right click the criterion label on the weighting ruler that you want to use as the standard (say Cost), and select Set Right. The red bar is now associated with the Cost criterion.

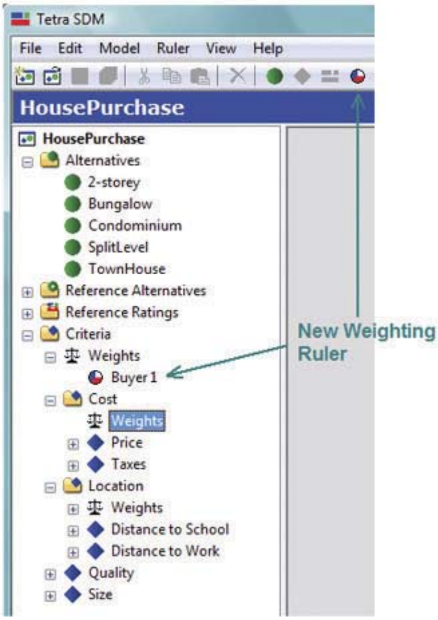


Figure 6.4 Creating weights.

- Click on the Cost criterion on the ruler, and drag it somewhere to the right of all the other criteria. Then right click in a blank area of the ruler window, and select Expand. This changes the view of the ruler for easier visualization – it does not alter the values of any of the weights.
- Drag the label for one criterion at a time in the figure, until its weight (or relative importance) relative to Cost is where you want it. For example, suppose that you consider the Location of the house to be 80% as important in your decision-making as the Cost factor; then drag the Location label until the proportion of the blue bar to the red bar is 80%, as shown in Figure 6.6.
- Repeat this procedure for the remaining two criteria, assuming for this exercise that house Size is 50% as important as the Cost, and that the Quality criterion is assigned a 40% weight relative to Cost.
- (Optional) You may enter more precise values directly into the Tabulated Weights cells in the lower pane. These proportions are reflected in the Ruler Window.
- Note that it is only the relative values of weights that are significant. For example, the same result would be obtained if two criteria, Size and Cost

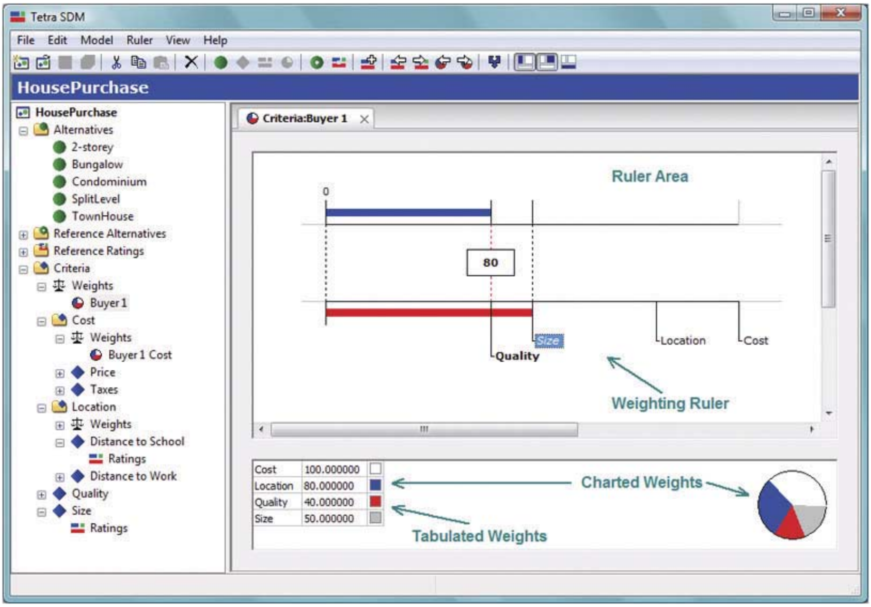


Figure 6.5 Assigning weights: size criterion.

were given weights of 1 for Size and 2 for Cost or 50 for Size and 100 for Cost.

Tetra actions to assign the weights for the sub-criteria:
This procedure is essentially the same as the preceding step, except for two variations:

- Start by clicking on the Weight label in the criteria tree that is associated with the sub-criteria for which you want to assign weights. As shown in the figure, to assign weights to the two sub-criteria associated with Cost, right click on the word Weight under the Cost branch, select New Weighting Ruler, and then continue as above.

- When right clicking on the weighting ruler to add criteria, only the set of corresponding sub-criteria will be available (Price and Taxes in this case).

- To complete the weighting of sub-criteria, set the sub-criterion Taxes to be 20% of the weight of Price, and the sub-criterion Distance To Work to have an importance weight of 40% relative to Distance To School.

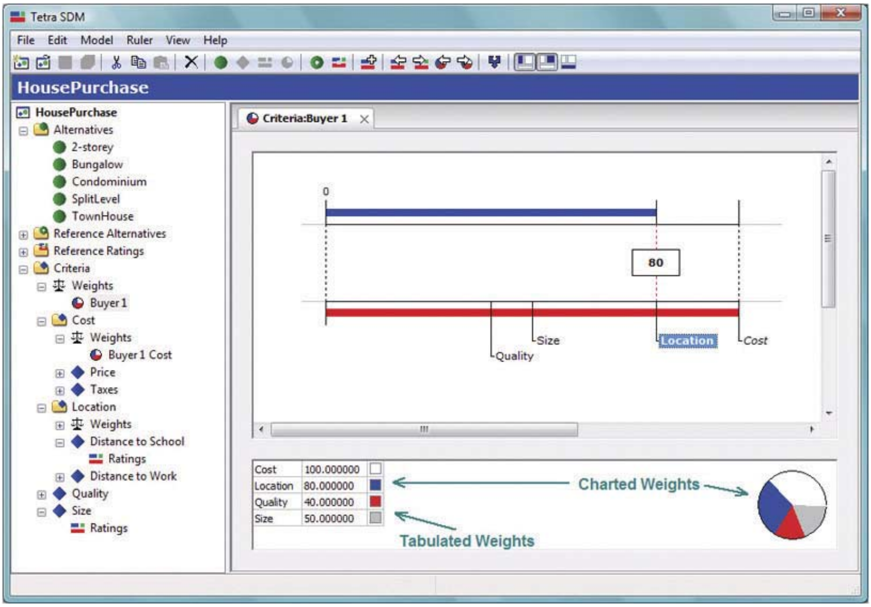


Figure 6.6 Assigning weights: location criterion.

A different perspective to entering weights is to think in terms of ratios. For example, if you consider Price to be 5 times as important as Taxes for making your decision, you could enter a value of 1.0 in the Taxes cell in the tabulated weights, and a value of 5.0 in the Price cell (Figure 6.7). The length of the red and blue bars in the weighting ruler will adjust accordingly. (You can then expand the ruler to give the figure above).

As you work on weighting (and, later, on ratings), remember that changes you make to rulers are not automatically saved as you go along. You must either close the ruler (the X in the ruler tab), or save the changes with the Save Ruler or Save All Rulers commands in the Ruler menu.

Step 6 – Establish reference alternatives for each criterion.

At least two reference alternatives must be defined for each criterion on which the alternatives (the five houses) are rated, in order to establish a scale. This can be done by selecting a reference rating ruler or by associating actual or hypothetical objects with the default reference objects 'Z' and 'H' where 'Z' is an alternative or object that scores zero for that criterion and 'H' is an object that scores 100 for that criterion. Note that the reference alternatives are objects, i.e. their definition requires nouns rather than adjectives.

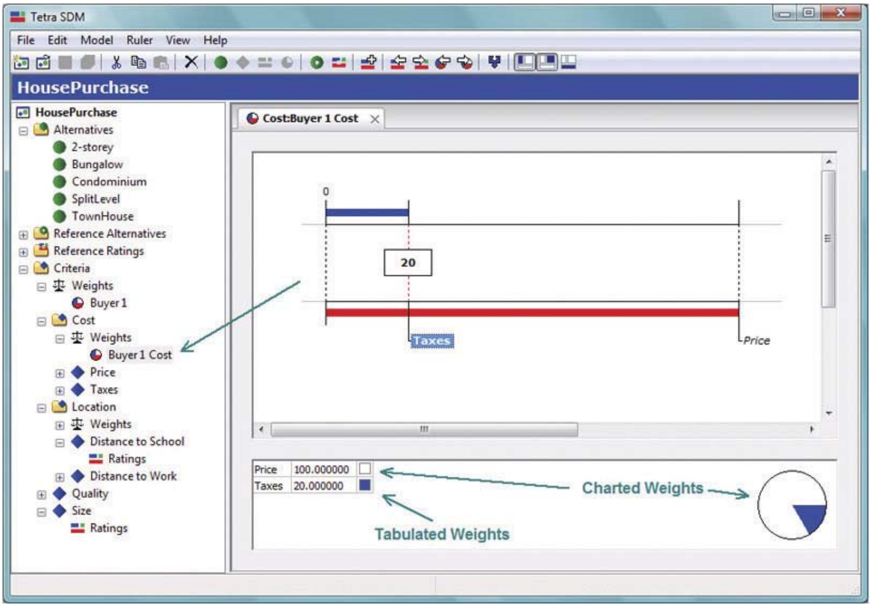


Figure 6.7 Assigning weights in terms of ratios.

- Using hypothetical alternatives: For example, a hypothetical 'Z'-object for the Quality criterion could be a squalid bachelor apartment and a hypothetical 'H'-object for the Quality criterion could be a mansion.

- Using actual alternatives: Another way to establish 'Z' and 'H' reference objects is to use two of the current alternatives. In our example, the 'Z'-object for the Quality criterion could be the townhouse, and the 2-storey house may serve as 'H'-object.

There are no Tetra actions required for this step - all that is needed is a clear definition of the reference alternatives for each of the six end-criteria, so that when ratings are made in the next step, they are done relative to these reference objects. Figure 6.8 shows how these concepts relate to the rating tools which will be invoked in the next section.

Suppose that the extreme alternatives associated with each of the six criteria are as stated in Table 6.1.

Note that for Price, the 'H'-object is the cheapest alternative and the 'Z'-object is the most expensive. For Distance to School, the 'H'-object was chosen as the closest alternative and the 'Z'-object is the farthest away.

In some decision-making situations, an Evaluation Plan is set up for the purpose of assessing future alternatives. In this case, the criteria are defined,

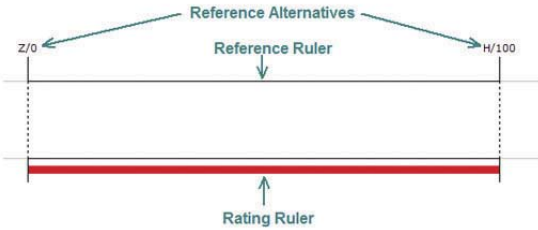


Figure 6.8 Reference alternatives.

Table 6.1 Extreme alternatives.

Criteria	Bottom	Top
Price	2-storey	Townhouse
Taxes	2-storey	Condominium
Distance to School	Bungalow	Split-level
Distance to Work	2-storey	Condominium
Quality	Townhouse	2-storey
Size	Condominium	2-storey

weights selected, and reference alternatives are established in advance. Since the actual alternatives are not known when the Evaluation Plan is set up, hypothetical alternatives must be used to define the reference objects in the Evaluation Plan for each criterion.

Step 7 – Rating the alternatives against each criterion

All of the alternatives (the five houses) must be rated according to each of the six end-criteria.

If you are using Tetra GDM, this step is carried out by each of the Decision Makers involved. After you finish working through this guide as the Model Owner, create another Decision Maker, close the model and reopen it as this Decision Maker. Enter ratings for that Decision Maker using the same process described here, then close and open the model as the Model Owner again, so you can solve the model again to see the changes in the combined ratings.

When you open the model in Tetra GDM you have the option of opening it in 'Exclusive Mode.' This can only be done by the Model Owner, and allows the model owner to view (but not modify) the ratings of other Decision Makers. This is particularly useful when reviewing ratings as a group, as it makes it easy to move between and compare the ratings of all the Decision Makers involved in the process.

Figure 6.9 Creating rating rulers.

Tetra actions to rate alternatives against criteria:

- Right click on any criterion in the criteria tree (such as Quality) and select New Rating Ruler (or click on the new rating ruler icon in the menu bar) to create a new rating ruler. You may enter a name for this set of ratings if you choose (such as BuyerName).
- Double click the label for the current set of ratings ('BuyerName' in this case) in the criteria tree and a blank rating ruler will appear in the ruler area.
- Right click anywhere in the ruler area, select Add Alternative, then Add All.
- Using values from the table below, enter the ratings of the alternatives for each of the end-criteria. Note that for some criteria, such as Price, a higher value is worse; so in this example the more expensive 2-storey house is rated the lowest on the Price criterion.

Once you have the alternatives on the rating ruler, you can specify values for the ratings of each alternative in two ways:

- You can enter numerical values into the value entry table below the ruler.
- You can drag the alternatives along the ruler to specify the ratings.

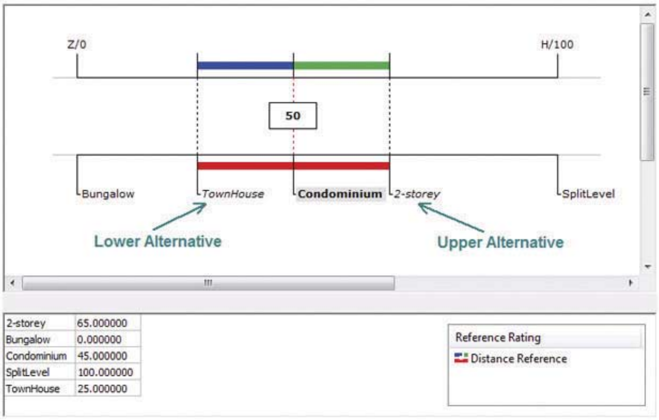


Figure 6.10 Rating alternatives.

In addition to specifying ratings for alternatives, Tetra also lets you specify relative ratings between alternatives. To do this, lower and upper alternatives are used. By default, the value 0 (reference alternative Z/0) is used for the lower reference alternative, and the value 100 (reference alternative H/100) is used for the upper reference alternative. To choose a different lower or upper reference alternative, right click on the alternative or reference alternative you wish to use and choose Set Left or Set Right, respectively. In the figure, the Townhouse has been set to be the lower alternative and the 2-storey has been set to be the upper alternative.

In the rating ruler, the red bar indicates the difference between the upper and lower alternatives. When an alternative is selected, the blue bar indicates the difference between this alternative and the lower alternative and the green bar indicates the difference to the upper one. Furthermore, the value in the box on the line above the selected alternative shows the relative rating of the selected alternative as compared to the lower and upper alternatives (the ratio of the blue bar to the red one). In the figure we see that the Condominium is rated as being half-way between the Townhouse and the 2-storey with respect to this criterion. You can set the lower and upper alternatives back to the value 0 or the value 100 by right clicking anywhere in the rating ruler and choosing Clear Left or Clear Right, respectively.

Figure 6.10 shows what the rating ruler for one of the criteria, Distance to School, might look like.

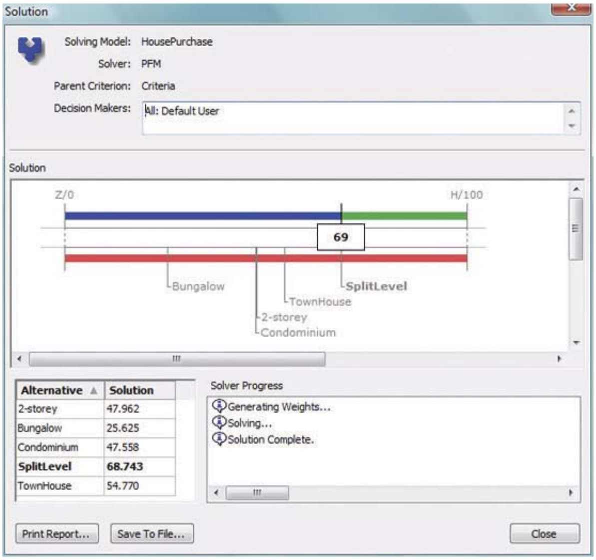


Figure 6.11 Solving the model.

Step 8 – Solve the Model to Determine the Preferred Alternative

Remember that, in Tetra GDM, you must be the Model Owner, and have the model opened in exclusive mode, in order to perform this step.

The preference function modeling methodology can now be applied to rank the five alternatives (the houses) according to their rating on each of the six criteria, and the relative importance of the criteria.

Tetra actions to run the solver (Figure 6.11):

- Click on the Solve icon in the menu bar.
- The results of the numerical ranking, the Overall Preference Scale, are shown in the solution output dialog.
- Using ratings and weightings similar to those presented in this example yields an overall preference scale such as the one in the screen capture. According to this result, the best decision is to buy the Split-Level house.

It should be noted that the Tetra software presupposes that the alternatives are known. That means it offers and evaluation method, not a design method in which the alternatives are not known *a priori*. Binnekamp (2010) has developed a methodology enabling a design to be based on the preferences of stakeholders, thereby making it possible to involve them already in the design stage of a project.

6.3 An application of preference measurement in the construction industry

The importance of correct scaling of preferences is illustrated in the following application in the construction industry.

A reputable construction company used to address their customers with a yearly survey to measure their perception of the quality of the firm. Respondents were requested to give a grade, on a scale of 1 to 10, for the performance of the company in regard to various criteria that were considered to be relevant:

- Communication;
- Reliability;
- Delivery times;
- Eye for customer's interests;
- Quality control;
- Image.

On all criteria the company scored well above seven, so everything seemed to be in order. Until, that is, one of our graduates (Sneekes, 2003)raised the question: 'How do you know that your major competitors don't score an eight?' After all, to be selected in a bidding procedure, to be 'good' is not good enough. One has to be perceived as better than the competing candidates. The answer was: 'We don't know, but we cannot ask our customers how we score compared to specific competitors.' This problem was resolved by asking each respondent to provide three scores per criterion:

- Score of the firm;
- Score of the worst competitor the respondent had ever experienced;
- Score of the best competitor ever experienced.

There was no need to disclose the identities of those worst and best performing competitors. This simple change in the survey made it possible to establish how the company scored in comparison to the competition. The company's objective was to score at least in the top quartile in all criteria. With the assumption that performance of competitors follows a normal distribution, the relative position of the firm on each criterion could be assessed. It turned out that on two criteria the firm scored just below the top quartiles, suggesting a need for managerial measures in those areas.

This example from practice shows how easily one can fool oneself if the measurement scales of preferences are not properly defined. The earlier survey results were completely meaningless, if not misleading. As becomes apparent, there exists no independent scale on which preference can be measured. There is no (known) zero-point (origin) representing the lowest preference.

One cannot say: 'I like my new car twice as much as my old one.' To measure preference correctly, measurements have to be taken relative to two arbitrarily chosen reference points. What is measured is the ratio of differences and this operation is independent of the chosen origin and selected unit of measurement.

7 Use of the quality classification in the construction industry

A construction company is a Jobber, delivering a capacity, not a product, to build something. As we have seen in Section 4.3, its strategic quality aim is to realize the subjective wishes of the customer. In general, these wishes are:

1. Functionality, delivering something that works as intended;
2. Commissioning on time;
3. Cost within budget.

This means that one should not focus on getting execution in line with specifications, rules and regulations, but on letting execution cover as closely as possible relevant quality as required for functionality (Figure 4.3). In the following sections, we describe how our concept of the seven categories of quality was applied in the Nanhai project, a US$ 4.3 billion construction project of a petrochemical plant in the Guangdong Provence of P.R. China (Van Gunsteren, 2011).

7.1 Prerequisite for the implementation of any new concept: the product champion

For the construction industry, the principle that compliance to specifications should be subordinated to real quality, i.e. fitness for purpose, constitutes a new concept. New ideas do not sell themselves. They need a product champion, also called organizational guerrilla, to achieve acceptance. The product champion fights with all available means for the acceptance of the innovation and is prepared to risk his reputation or even his job for it. A product champion is a prerequisite for the implementation of anything new in order to overcome the fear of innovation, which prevails in every organization. Machiavelli (15th century, in The Prince):

> *There is nothing more difficult to take in hand, or more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things because the innovator has for enemies all those who have done well under the old conditions, and only lukewarm defenders in those who may do well under the new.*

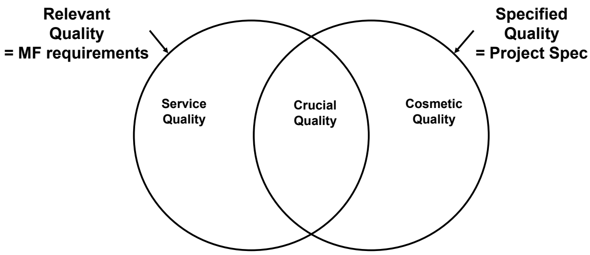


Figure 7.1 Specs never cover relevant quality.

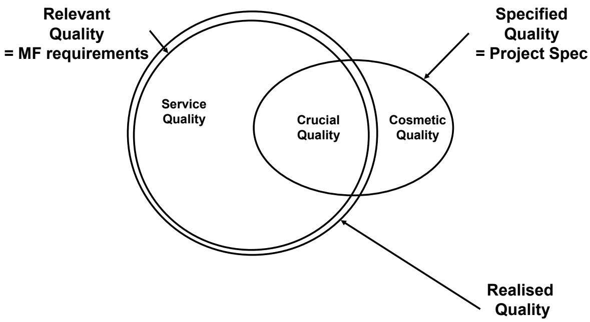


Figure 7.2 The ideal world.

Fortunately, our quality concept found its product champion in the person of Ton Sluman, who understood it and applied it in his daily work. He attached the pictures of the circles with associated one-liners on the publication board on the site (Figures 7.1, 7.2, 7.3, 7.4, 7.5).

Support for the product champion's approach was provided not only by the project team but also by the CEO of the entire project (Simon Lam). The prerequisite for acceptance of *a new order of things*, a product champion with the blessing of a benefactor high up in the organization, being satisfied in this case has been a key factor for its success.

7.2 The use of the quality circles

The Venn diagrams of our quality classification, usually referred to as *quality circles*, were used for three different purposes:

1. *Accepting Chinese standards* whenever possible. For instance, accepting them for buildings not essential to the process of the plant, and relaxing the offshore Shell standards to Chinese ones for the jetty in the middle of Daya Bay.

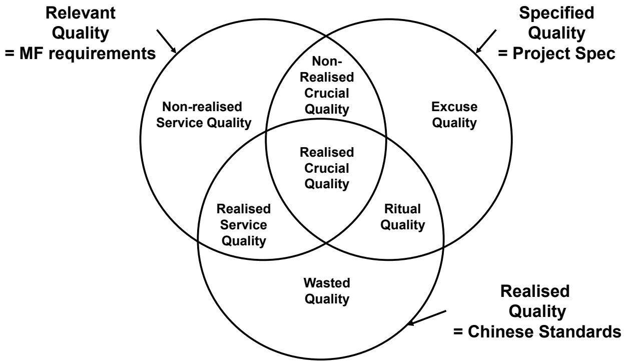


Figure 7.3 You do not get what you want or specified.

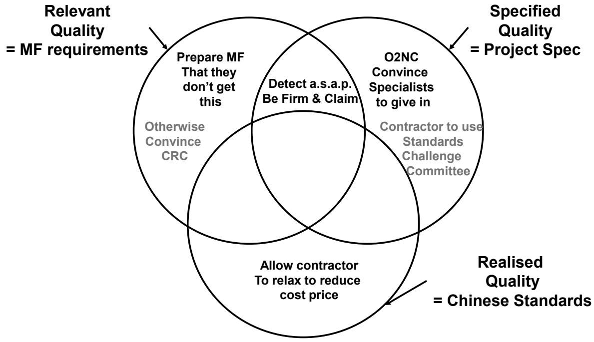


Figure 7.4 Communication is key.

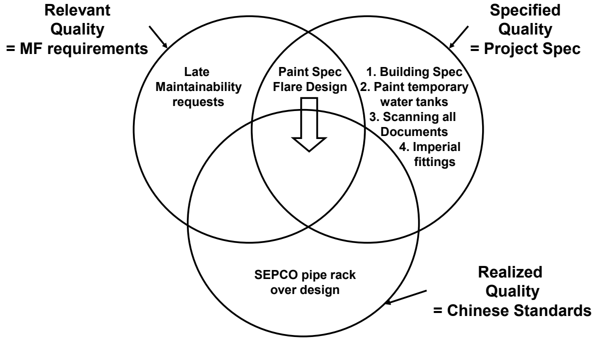


Figure 7.5 Examples.

2. *Changing scope*. Many small changes done in process to increase reliability and reduce costs. For instance, delaying the railway, since it could not yet be used by the future refinery next door and outsourcing the air splitter to Praxair adjacent to the site, who could make also nitrogen and oxygen for others, thereby utilizing economies of scale to the benefit of both parties.

3. *Managing expectations of maintenance departments* by providing them with records of non-conformance from original specifications for later use in inspection programs and debottlenecking studies.

Quality-related issues arose in all seven categories of quality, as is illustrated in the following examples:

1. *Non-realized service quality* (relevant, not specified, not realized). Hidden deficiencies which surface in the first commissioning phase and first years of operation.

2. *Non-realized crucial quality* (relevant, specified, not realized). Serious issues arose with the quality of underground water cooling lines due to sub-standard design by Chinese vendors, irregularities with licenses, and construction not according to specifications but to Chinese practices of drains. Awarding contract after competitive tendering to four different contractors entailed losing central control. Ultimately, a fall-back system (based on steel instead of glass fiber reinforced Epoxy) was installed, but so far has not been used.

3. *Realized service quality* (relevant, not specified, realized). Example 1: Because of accidents elsewhere, spheres for ethylene and propylene storage were under scrutiny. German materials were used which were better than prescribed by the Chinese authority for this matter. Nevertheless, a lobbying battle turned out to be needed for their approval. Example 2: Dredging by Chinese contractors without dumping. Monitoring for suspended soils and other environmental impact done by Boskalis was better than specified. Even a living choral was relocated. But Chinese authorities did not believe there had not been any dumping, invoked the license and wanted penalty fees to be paid. Instead of giving in to this, a budget was approved for additional inspection at a dumping station, twenty miles out of the coast in accordance with the London dumping convention. Apparently, it is so unusual to do better than specified in regulations that this evoked problems instead of appreciation.

4. *Wasted quality* (not relevant, not specified, realized). Overdesign in engineering is quite common in China. The government holds engineering,

which is kept completely separated from construction, responsible for eventual disasters. Chief Engineers of Chinese design institutes, trying to reduce the risk of sanctions (including prison sentence), tend to be conservative rather than cost-conscious. Construction, by contrast, is in China always trying to cut costs by compromising quality. For this reason, the government established specialized supervision companies to check on 'construction to design'. In the Nanhai project, the steel constructions for the power plant were overdesigned by Sepco, a Chinese power and construction company.

5. *Ritual quality* (not relevant, specified, realized). A big investment was made in the water treatment and solid waste disposal facilities. A twenty kilometer pipeline was laid under water to discharge at a point of maximum turbulence and mixing with tidal movements. Other local parties in similar situations refrained from such expensive measures, indicating that this was a case of ritual quality.

6. *Realized crucial quality* (relevant, specified, realized). Many issues surfaced in this category. One example is small bore connections: Chinese contractors were not sufficiently aware of the specifications and did not comply. Corrections were made on time with special inspection tools. A second example is flare construction, which was a copy of the plant in Pernis which can be lowered during operation. This requires sliding tolerances in millimeters. The Chinese vendor, not being sufficiently warned on this point, produced power tower quality with tolerances in centimeters. It was redone at the site, on time but at extra cost.

7. *Excuse quality* (not relevant, specified, not realized). Example 1: British scaffolding was specified, but Chinese standards were actually good enough. Halfway, Chinese standards were adopted with full enforcement of implementation. The benefits in regard to cost and time created goodwill with the contractors. Example 2: The project team considered the Shell safety systems to be overdone and took the liberty to not fully implement them, which proved to be justified in the start up. Example 3: Temporary water tanks were specified to be painted, which requirement was waived by the project team. Example 4: Buildings were specified with Shell standards. Two contractors for twelve buildings were allowed to build according to Chinese standards (with the exception of the blast proof control rooms). Example 5: Some of the as-built documentation specifications were considered to be overdone and were waived.

For the authorization of the quality related changes, two committees were in function:

1. Change committee on scope changes, chaired by the CEO (Simon Lam).

2. Standard challenge committee, chaired by the construction director (Frans van Gunsteren), which always involved the end user in its decision making.

Giving away cosmetic quality and wasted quality, or exchanging these for service quality, yields substantial cost savings for the contractors concerned and generates valuable goodwill with them. It is essential however that the changes are authorized at the right organizational level.

7.3 Trade-offs between quality, costs, and schedule

In construction projects, trade-offs must always be made between quality, costs and schedule. Quality is usually perceived as being defined by the project's specifications. Costs are supposed to be specified by the budget. The schedule is assumed to be given by a network planning aimed at completion on time. As a result, prevailing management focus in construction projects tends to be concentrated on cost and schedule, with quality management limited to implementing contractual specifications.

When construction projects become large and complex, however, many relevant matters are reflected neither in the contractual specifications nor in the budget or the network planning of the project. As a result, functionality suffers under the prevailing management approach. A costly effort must still be made to ensure that unspecified, yet relevant, quality is realised in the project. Inevitably, this leads to substantial overruns in time and money.

Attempts to avoid these overruns in time and money have resulted in ever more exhaustive specifications, budgets and schedules, but these turn out to produce disappointingly little effect. This is not surprising in view of the fact that the every-day reality is too complex to be realistically reflected in specifications, budgets and schedules. Even if that would be at all possible, it is naive to expect that subcontractors will take the time to fully read and digest such voluminous documentation, particularly within the limited time of the bidding phase.

In short, the usual preoccupation with cost and schedule does not work. As with the arts of Zen – archery, sword fighting, flower arranging – one has to remove the ultimate goal – the arrow hitting the target, striking the opponent, achieving the most beautiful flower arrangement – completely from the mind and concentrate on quality as required by functionality and not only as specified in contracts and consider cost and time of completion as outcomes of a process, which can only indirectly be controlled.

8 Quality in architecture

An architect is a consultant advising his principal in building related matters. As we have already pointed out in Section 4.4, this means that his advice or his design should comply as much as possible with the problem definition of his customer.

In general, the problem definition, as specified in the bill of requirements, includes two different sets of requirements:

1. Efficiency-related requirements: use of floor space, energy consumption, logistics, parking space, etc.

2. Beauty-related requirements: eye-catching shape, prestigious entrance hall, impressive façade materials, etc.

An architectural design is always a mixture of the two. When they are not in balance, dissatisfaction and disappointment will be the result.

For instance, a bank had their offices evaluated on the basis of the REN-norms (Real Estate Norms, which are not normative at all but descriptive, since they are no more and no less than the result of an extensive regression analysis of a vast number of existing buildings). The bank's Düsseldorf office in Germany was evaluated as a poor design. That is, according to the REN-norms. The management of the bank pointed out that in order to be a serious party in big business in Germany, a prestigious office in Düsseldorf is a *conditio sine qua non* and they considered the associated cost as a sound investment.

In practice, also the other extreme often occurs: choosing a beautiful architectural design that later turns out to be infeasible. The design has then to be modified several times to regain a minimum degree of fitness for purpose. At hindsight, another design would have been the most preferred one.

The main question then is: how can we define this *balance* between beauty-related and efficiency-related requirements? Consider these two sets of requirements to be two top-level decision criteria. We can then attach weights to them and determine the scores of different designs on these criteria. These scores represent a decision maker's preference for different aspects of the designs. Chapter 6 describes the procedure for measuring preference with the PFM algorithm to determine an overall preference score for each design.

Weights represent the importance of a criterion with respect to other criteria. Problems occur when a design scores low on a criterion that is considered important (by one or more of the stakeholders). A design that scores very low on beauty-related requirements while the client considers this criterion of importance is problematic. Conversely, a design that scores very low on efficiency-related requirements while the client considers this criterion of importance is also problematic.

We argue that a design which scores low on either beauty-related or efficiency-related requirements is not in balance because in architecture both requirements are normally of importance to one or more stakeholders.

As an illustration, three cases are described in the next sections:

1. Renovation of the Stedelijk Museum (for contemporary art) Amsterdam;
2. Development of the new office of the broadcasting organization VPRO.
3. The Øresund link connecting Sweden and Denmark.

The first two illustrate designs that are not in balance, the last illustrates a balanced design.

8.1 The Stedelijk Museum Amsterdam

The following reconstruction is largely based on Sanders et al. (2003).

The Stedelijk Museum Amsterdam (SMA), designed by the architect A.W. Weissman, opened its doors in 1895. The museum was founded by a group of Amsterdam citizens. In the period 1945 to 1962, during the time that Willem Sandberg was the managing director, it established an international reputation as an institute focusing on the cutting edge of modern and contemporary art.

The museum's strengths are its contemporary art collection which approaches that of the Museum of Modern Art, Centre Pompidou and the Tate. It has a reputation for setting trends and for its openness and dynamism. Its main building is well located in the very center of Amsterdam and its archive and library are of high quality.

Its weaknesses were closely related to the deteriorating condition of the building. The building had climate control problems and part of its collection had to be moved to a secondary location outside the city center. The museum was considered to lack a coherent vision and to focus only on the quantitative aspects of exhibitions, not qualitative aspects. Visitor numbers were declining and as a result the museum had a hard time finding (financial) support within the municipality to extend and renovate the building.

Overview of plans made

In 1991, the municipality decided to ask four architects to make plans for extending the existing building and commissions Venturi to make final plans based on a budget of approximately 15 million euros. Although Venturi finished the final design in 1994, the municipality decided not to go ahead with these plans as they required a budget of approximately 35 million euros. In

1995 the municipality commissioned the Portuguese architect Siza to make a design (Siza I) for the extension which he finished in 1996, requiring a budget of approximately 25 million euros. As the existing building, by that time, also needed renovating and the floorspace for exhibitions was too limited, the museum, in collaboration with the municipality developed five alternatives for extending and renovating the museum. The municipality realized that its preferred alternative required a budget of 90 million euros and decided that part of the budget needed to be financed by other parties than the municipality. They commissioned Siza to make a design (Siza II) based on that alternative. The museum, in particular its staff, was disappointed with Siza II as essential elements of its organization are moved to the secondary location, a large amount of floorspace is allocated for commercial activities and because of logistic problems. They decided not to go ahead with Siza and devised a new plan named 2A/B but even this plan was not approved as the financial consequences of it were unclear. The process then stopped.

Conclusion

The Siza II design is an example of a design where efficiency-related requirements are important to the municipality and users but where largely ignored by the architect. Beauty-related requirements, important to the architect, became dominant. Thus, this design was unacceptable to the municipality and users. The stale-mate situation was resolved when beauty-related requirements became less dominant and efficiency related requirements were also seen as important. See Binnekamp et al. (2006) for how this was achieved.

8.2 The new office for the broadcasting organization VPRO

The new office for the VPRO broadcasting company, called Villa VPRO was completed in 1997. The dissatisfaction of the most important stakeholder – the people who have to work in the building – has been extensively documented in a booklet published three years after commissioning (Paans, 2000) as well as in the press. How the design team developed innovative solutions has been described by Roelofs (2001) and, looking at how the project was managed, by our Open Design group (Binnekamp et al., 2006, pp. 137-150). The essence of the development process is reproduced below.

The design by MVRDV architects was based on an audacious architectural concept, which required innovative solutions from all parties involved. The main characteristic feature of the design was the architectural open space concept: open floor areas with open views from one floor to another. Two of the architects involved – Maas and Van Rijs – had previously worked at the OMA of Rem Koolhaas, who had applied a similar open space concept in his design for the competition in 1993 for the Bibliotheque Jussieu in Paris.

The following key issues would have to be resolved for the realization of the open space concept (Roelofs, 2001):

- First, there is the issue of fire protection and escape routes. Once ignited, a fire could spread through the building very quickly. Corridors with fire doors would clearly be in conflict with the open space concept.
- Second, the daylight distribution in the building constituted a serious problem. The daylight in some working locations would not meet the prevailing regulations for daylight at the working place at all.
- Third, certain areas would have to be protected against too much sunlight.
- Fourth, the installations for ventilation and heating would have to be designed in such a way that all the connected open spaces would be properly ventilated and heated.
- Finally, noise hindrance and acoustics are critical in such an open, connected space. A broadcasting company is quite different from, say, a software development firm where people are quiet behind their computer screens. A lot of verbal communication and telephone conversations are inherent to the mission of a broadcasting organization such as the VPRO.

The first four of these issues were addressed successfully, the fifth one, noise hindrance and acoustics, was not. It was considered sufficient to provide for some quiet rooms and for an extra budget, which would allow corrective measures to be taken after commissioning, such as the application of noise damping materials at critical locations. Not addressing this issue adequately made it unsuited to its very purpose: providing an adequate working place for an organization of (top) programme makers for television and radio. The architects and management persisted in their view that the design reflected the practical requirements of the users, who in turn maintained that quite the opposite was true. The result has been that most of the people who have to work in the building are extremely dissatisfied and disappointed.

Immediately after the commissioning of the building in June 1997, a stream of serious complaints from the users about noise and lack of privacy began. Employees started to correct the situation right away by building their own 'walls' with cupboards, boxes and curtains (Fig. 8.1 and Fig. 8.2).

The fact that the key issue of noise and acoustics – and to a certain extent also the lack of privacy – was largely ignored and played down during the design phase of the project was not just a coincidence. The ambition of realizing a daring architectural concept brought with it that anything that could kill it was taboo: not open for discussion because of too painful consequences.

Figure 8.1 Interior VPRO office after the building was completed.

Figure 8.2 Interior VPRO office after modification by the user.

The architects could not ignore the other four key issues. Fire protection and escape routes concern personal safety which no one is prepared to compromise. Daylight distribution and sun protection affect the very nature of the work of an architect: playing with space and light. Installations for heating and ventilation simply cannot be left out.

Noise hindrance and privacy, by contrast, do not affect safety and are subjective in the sense that different individuals perceive them differently. They are, therefore, linked to the mission and culture of the organization concerned.

Conclusion

This case is similar to the previous example where beauty-related requirements were dominant. Efficiency-related requirements, important to the users, where largely ignored by the architect and client. Beauty-related requirements, important to the architect and client, became dominant. Thus, this design was unacceptable to the users. We argue that a change of concept during the initial design phase, scoring relatively high on both beauty-related requirements and efficiency-related requirements would have been a better choice.

8.3 The Øresund Link

The Øresund link between Sweden and Denmark was opened to traffic on the 1st July 2000 (Booij et al., 2012). The link is 16 km long and consists of a bridge, a submerged tunnel and a man-made island. The link consists of a fixed road and rail connection between the two countries.

Plans to link the Øresund region have been around for centuries but were always confronted with a strong opposition. In the 19th Century the plans were opposed by nationalists in both countries and more recently by environmentalists concerned with the impact that construction would have on the wildlife in the Øresund region. However, the governments of both Sweden and Denmark felt that by linking Malmö and Copenhagen, they would create a region with increased cultural, educational and economic links.

In recent years the rate of unemployment has been higher in Malmö than in Copenhagen. With the construction of this link it is now possible to work in one country and live in the other. As housing is cheaper in Malmö than Copenhagen, people are now able to purchase houses in a cheaper area and commute across the bridge to work (Shrubshall, 2007). With Europe becoming increasingly borderless the governments of Sweden and Denmark see the Øresund region as a model of integration and cross border cooperation for the rest of Europe. The vision is to establish a powerhouse which will make the region more attractive to live, visit and work in.

Alternatives

The question is asked: 'What is the best way to cross the water in order to connect the two regions?'. Three alternatives are set out. The first and the second are two completely different solutions to the problem, the third one is a combination of the first two.

The first alternative will provide a 16 kilometer long tunnel from Copenhagen to Malmö. With an average sea depth of the Øresund in certain areas this is a possible solution. The solution is shown in Figure 8.3.

The second alternative is to make by far the longest bridge of its kind. This bridge needs to be high enough for ships to pass underneath the bridge, because otherwise it will block an important sailing route. This alternative is shown in Figure 8.4.

The third alternative is the one which was finally built. This is a combination of both alternatives 1 and 2. But how does a tunnel turn into a bridge in the middle of the open sea? The solution here is to make an island from scratch. This results in a four kilometer long tunnel, a four kilometer long island and an eight kilometer long bridge, which together will form the Øresund Link. This alternative is shown in Figure 8.5.

Criteria, reference alternatives and scores

The different alternatives were compared using beauty-related and efficiency-related top-level decision criteria. The first criterion is beauty-related, the rest are efficiency-related.

The way the design is perceived as an icon

With the building of the link, the Øresund region must become an attractive economic region where two regions are filling up each other's needs: Sweden provides houses and Denmark provides jobs. By the combination, a strong economy can be established. In order to emphasize this importance, the governments of both countries strongly preferred an icon for the region. One gesture which was unique for the region. A symbol for the region which would be recognized by the entire world as the symbol of the Øresund region.

Safety towards existing systems

The Øresund Link has to be built within the framework of the existing transport methods of the area. The two main transport methods which have their influence on the design are (1) the Copenhagen International Airport, where planes will fly very low on their approach and departure, and (2) ships which

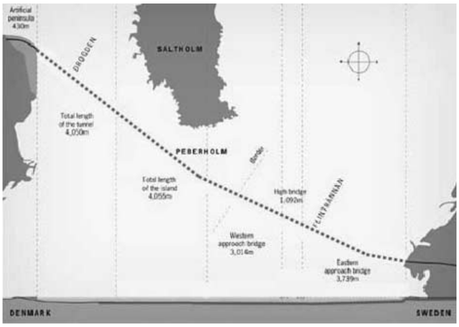


Figure 8.3 Alternative of a bridge.

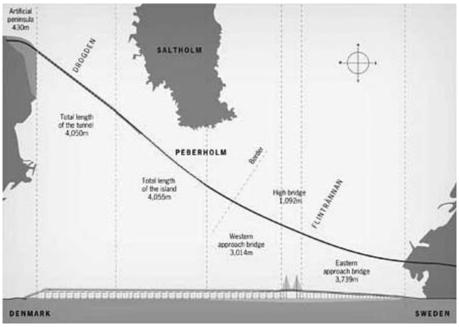


Figure 8.4 Alternative of a tunnel.

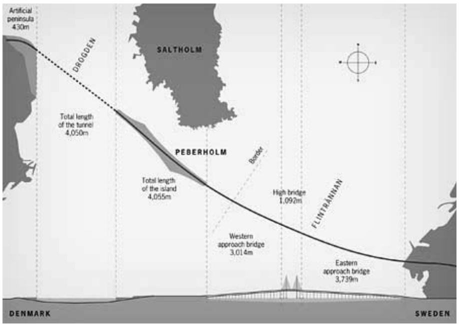


Figure 8.5 Alternative of a combined bridge and tunnel linked by an island.

cross the Øresund and should not be blocked by the design or emerge as a safety risk for the design. This criterion is therefore divided in two sub-criteria: collision risks of ships and collision risks of airplanes.

Costs

Costs are divided in two sub-criteria: construction costs and maintenance costs of the bridge.

Road safety

Road safety is expressed in one criterion: the road safety of the link. The road safety criterion is based on the fact that the numbers of accidents occurring in a tunnel differ from accidents on a normal (open) road. Especially in the entrance zone of a tunnel the number of accidents is high. Lots of redesigning of tunnels took place over the years to reduce this problem, but it is still visible in the numbers today. Multi-vehicle accidents with vehicles moving in the same direction are overrepresented in tunnels and bring along huge congestions (Amundsen and Ranes, 2000).

Flexibility

Flexibility relates to the possibility to expand the link. The Øresund Link connects two countries with their own problems: Sweden's shore needs more jobs and Denmark's shore needs more housing. But the success of this link is not totally predictable in advance, there may be a market for an expansion of this Link in the future. Expansion of a bridge is possible and has been done before, like the Angus L. Macdonald bridge in Canada or the George Washington Bridge in New York. Expansion of a tunnel is only possible if a total new tube is added. This is not only an expensive alternative, but also has some technical difficulties, because of the pressure distribution. For the third alternative there is no need to widen the island, because there will be enough space for an expansion.

For correct scaling, two reference alternatives are required for each criterion to define the scale from 0 to 100. These are shown in Table 8.1. The preference scores of the alternatives are given in Table 8.2.

Table 8.1 Reference alternatives

Criterion	Reference	Description
Collision risks of ships	Z/0	0 collisions each year
	H/100	5 collisions each year
Collision risks of airplanes	Z/0	Most unsafe solution (bridge)
	H/100	Most safe solution (tunnel)
Construction costs	Z/0	Most expensive solution (tunnel)
	H/100	Most inexpensive solution (bridge)
Maintenance costs	Z/0	Most expensive solution (bridge)
	H/100	Most inexpensive solution (tunnel)
Number of accidents	Z/0	Most unsafe solution (combined bridge and tunnel, tunnel)
	H/100	Most safe solution (bridge)
Possibility to expand	Z/0	Most difficult to expand (combined bridge and tunnel)
	H/100	Most easy to expand (bridge)
The way the design is perceived as an icon	Z/0	Channel tunnel
	H/100	Golden Gate bridge

Table 8.2 Scores of alternative designs on different criteria

Criteria	Beauty	Efficiency					
Sub-criteria		Safety		Costs		Road safety	Flex.
Sub-criteria		Ships	Planes	Constr.	Maint.		
Alt.1	0	100	100	0	100	0	40
Alt.2	70	40	0	100	0	100	100
Alt.3	90	80	90	40	60	20	0

Weight sets

In order to carry out a sensitivity analysis four different weight sets are defined.

Weight set 1 – Efficiency dominant

In this set, efficiency is dominant over beauty and all sub-criteria are considered to be equally important. The weight distribution is shown in Table 8.3. With the preference scores of Table 8.2 and the weights of Table 8.3, the over-all preference rating calculated with the PDM algorithm is as shown in Figure 8.6.

Weight set 2 – Actual situation, balance between Beauty and Efficiency

In this set, the actual situation is simulated. There is a great importance on the way the alternative is perceived as an icon and on the safety towards external systems. The weight distribution is shown in Table 8.4. With the preference scores of Table 8.2 and the weights of Table 8.4, the over-all preference rating calculated with the PDM algorithm is as shown in Figure 8.7.

Weight set 3 – Efficiency and Safety dominant

In this set, the situation is simulated in which the safety is the most important aspect. Therefore, all safety aspects have been weighted heavily. Due to the airfield in Copenhagen, the collision risk of airplanes has been doubled in this set. The weight distribution is shown in Table 8.5. With the preference scores of Table 8.2 and the weights of Table 8.5, the over-all preference rating calculated with the PDM algorithm is as shown in Figure 8.8.

Weight set 4 – Efficiency and Cost dominant

In this set, the situation is simulated in which the operation must be very profitable (because the Øresund Link is fully financed with private money). Therefore, maintenance costs and flexibility have been weighted heavily. Construction costs are by far the greatest investment and therefore weighted double in this set. The weight distribution is shown in Table 8.6. With the preference scores of Table 8.2 and the weights of Table 8.6, the over-all preference rating calculated with the PDM algorithm is as shown in Figure 8.9.

Note that only the actual situation (weight set 2) shows a balance with regard to beauty-related requirements versus efficiency-related requirements. The other weight sets are efficiency dominant.

Conclusion

The alternative design that was actually chosen for the project shows a balance between beauty-related and efficiency-related requirements. Looking from a safety-perspective (which was very important for the stakeholders), the gap between the alternatives narrows. Looking from an 'investor's' perspective, the best alternative would be a bridge. However, the mixture of the two and the importance of the icon for the region makes the alternative of the combined bridge and tunnel the best alternative.

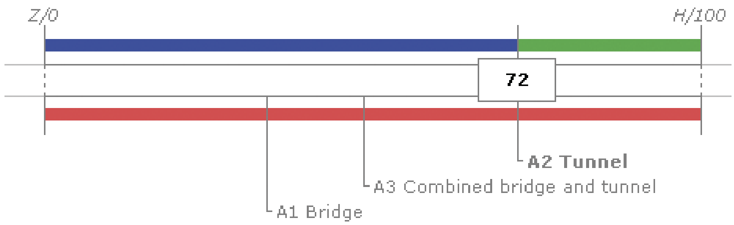


Figure 8.6 Overall preference rating (weight set 1).

Table 8.3 Weight set 1: Efficiency dominant

Criteria	Beauty	Efficiency					
Weights	50	200					
Sub-criteria		Safety		Costs		Road safety	Flex.
Sub-weights		25		25		25	25
Sub-criteria		Ships	Planes	Constr.	Maint.		
Sub-weights		50	50	50	50		

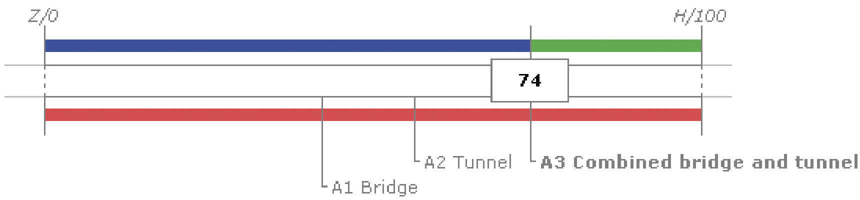


Figure 8.7 Overall preference rating (weight set 2).

Table 8.4 Weight set 2: Actual situation, balance between Beauty and Efficiency

Criteria	Beauty	Efficiency					
Weights	200	325					
Sub-criteria		Safety		Costs		Road safety	Flex.
Sub-weights		62		8		15	15
Sub-criteria		Ships	Planes	Constr.	Maint.		
Sub-weights		50	50	50	50		

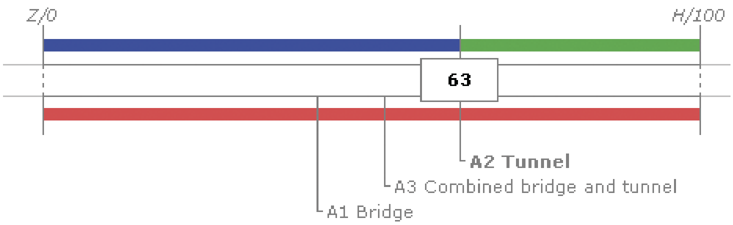


Figure 8.8 Overall preference rating (weight set 3).

Table 8.5 Weight set 3: Efficiency and Safety dominant

Criteria	Beauty	Efficiency					
Weights	50	475					
Sub-criteria		Safety		Costs		Road safety	Flex.
Sub-weights		42		5		42	11
Sub-criteria		Ships	Planes	Constr.	Maint.		
Sub-weights		50	200	50	50		

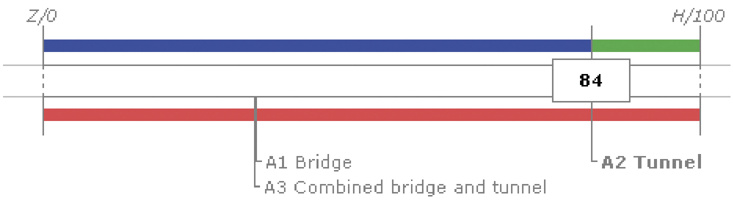


Figure 8.9 Overall preference rating (weight set 4).

Table 8.6 Weight set 4: Efficiency and Cost dominant

Criteria	Beauty	Efficiency					
Weights	50	500					
Sub-criteria		Safety		Costs		Road safety	Flex.
Sub-weights		10		40		10	40
Sub-criteria		Ships	Planes	Constr.	Maint.		
Sub-weights		50	50	100	50		

9 The essence

The mainstream of literature on quality control and quality assurance* is focused on getting the execution of engineering artefacts in line with their design as defined by drawings and specifications. Implicitly, the design itself is taken for granted.

The focus of author's approach, by contrast, is getting execution as much as possible in line with fitness for purpose. This approach recognizes the fact that design specifications and execution will never exactly cover all quality aspects that are relevant for functionality and fitness for purpose.

Design specifications as well as rules and regulations are supposed to enhance the quality of engineering artefacts but in reality often generate just the opposite. It simply is impossible to conceive specifications, rules and regulations that cover exactly what is needed for functionality and fitness for purpose.

Implications of this observation are:

1. In the case of a failure (breakdown or malfunctioning) always take into consideration all three basic aspects of quality: 1) Specified quality (design), 2) Realized quality (execution), and 3) Relevant quality as required by fitness for purpose.

2. Expect inadequate design to be the cause of failure rather than poor execution.

3. Don't suppose specifications, rules and regulations to be holy. If you would like to deviate from them, try to find out the reason for their existence and if that reason is not applicable to the situation at hand, dare to deviate and get exemption.

4. Focus on getting execution in line with fitness for purpose. Quality assurance should be focussed on this rather than on compliance with specifications. This requires a feedback loop from operational experience to design.

5. Be prepared to exchange *cosmetic quality* for *service quality*, which is beneficial to both vendor and buyer.

6. Removal of *cosmetic* and *wasted quality* can generate significant savings in raw materials and costs.

**Quality assurance* is a process-centered approach to ensure that the best possible products or services are provided. It is related to *quality control*, which focuses on the end results through testing and measuring characteristics of products and services.

Genuine implementation of these points can provide a long-term competitive advantage by establishing a reputation of delivering relevant quality at no more cost than strictly necessary.

Appendices

I Strategic classification of business units

I.1 Exploitation of R&D output: Four typical cases

A well-known rule of thumb indicates that roughly only one out of every ten projects completed by the R&D laboratory becomes a commercial success. Apparently, the proper exploitation of R&D output constitutes a major problem for most organisations. Although many reasons can be given for this, the most frequent one is undoubtedly a mismatch between the R&D output and the identity of the organisational unit entrusted with the commercialisation of that output or, confusion about the true identity of that unit. The classification of strategies presented here has proven its practical value in the analysis of such problems (Van Gunsteren, 1987). Before explaining it, let us consider some actual cases where the exploitation of R&D output appeared to be a problem.

Case 1:

Division A was one of eight divisions of a corporation with an impressive track record of technical achievements. The division produced gas turbines according to their own designs. Considerable investments were being made in the development of the product's next generation, which was expected to be superior in fuel consumption to any existing gas turbine. It then happened that the largest order in the market over the last three years was negotiated against tough international competition. Ultimately however, the President and the Chairman of the Board decided to let the order go to the competition since it could only be produced at a great loss in Division A, although still at a positive contribution to overheads.

As a result of missing this key order, the company had to lay off workers not only in Division A, but also in Division B, which would have been a major subcontractor for the manufacture of parts. The event made it clear that the company could no longer fund the development of the new generation entirely on its own, and the decision had to be taken to merge Division A in a joint venture with a leading gas turbine manufacturer.

Case 2:

Division X, responsible for the production and sales of controllable pitch propellers, was the problem child of a worldwide manufacturer of marine propellers. Its sister division Y, producer of monobloc propellers, had so far served as the cash cow from which the losses were funded. Division X was licensee of three different designs, but also wished to develop its own design. For this purpose, in spite of the loss-making situation, substantial investments for development were made. However, the output of the development effort seemed, again and again, to be too little and too late. The leading competitor had twice already managed to fill the gap in the market well before Division X was ready. What could the management do about this?

Case 3:

Division P manufactured several kinds of electrical equipment. The division originated from the workshop of the company's main line of business, being electrical installation contracting, which was taken care of by Division Q. For many years, losses in Division P were compensated by Division Q's profits. The strategy adopted by the management of division P to make the division profitable, was to develop and market new products. These were supposed to gradually take over production capacity that was initially used for subcontracted jobbing work for division Q and third parties. After some years one could observe:

1. More than 70% of the production was still jobbing work, i.e. work on customer specifications.

2. Many products had been launched, but in respect of both volumes sold and profitability, all had failed.

Two products were particularly illustrative for the situation:

1. *Emergency illumination.* Initially, this new product was a success. Substantial numbers of it were sold by sister Division Q. Eventually, however, other manufacturers copied the idea and brought cheaper versions to the market. Ultimately, even Division Q had to buy from others if they were not to impair their position in their own field.

2. *Electronic organ.* As a by-product of all kinds of electronics related development work, a new type of electronic organ was invented. The prototype showed, according to experienced musicians, several advantages compared to existing types. Nevertheless, not a single one was sold, because the company had absolutely no access to the essential distribution channels. Electronic organs are sold via shops of musical instruments and not via shops of electronic gadgets.

How could it happen that, in spite of genuine effort on the part of management and substantial investments, the strategy of engaging in new products produced, quite contrary to the intention, only losses?

Case 4:

The R&D department of an international contracting firm had developed an apparatus for sub sea soil investigation. The equipment was capable of carrying out soil investigations up to 6 metres into the seabed at a maximum depth of 200 metres. It could perform three functions: drilling, sampling and Dutch cone penetration.

Its use was primarily intended for sub-sea soil investigation for dredging operations, but it could also be used in various offshore applications, such as foundations for offshore constructions and projection of sub-sea pipelines. After its first successful application, a policy for its further commercialisation had to be developed. Three options were open to the management:

1. Give exclusive rights to the corporation's dredging company.
2. Give the rights of exploitation to the firm's survey and soil investigations company (actually acting more in the capacity of an engineering consulting company).
3. Give the rights of sale and production to a hardware manufacturer.

Finally, a mixture of options 1 and 2 was chosen. The survey company would exploit the equipment by hiring it out to the dredging company as well as to the third parties but the dredging company would have a right of veto in respect of its use by competitors. During the following years, the survey company profitably hired out the equipment and also used it as a leverage to sell engineering services. However, the improved Mark II and Mark III models, which the development team had hoped for, were not produced and the equipment's potential for the off shore industry (it could drill a hole in the sea bed at one tenth of the costs involved when using a manned diving bell) was never realised. Subsequently, after three years and thorough intelligence work, competitors produced their own equipment based on the same concept. How could it happen that no more advantage was obtained from the technological edge that the company had?

I.2 Classification of strategy

These and numerous other cases have led me to the conclusion that to establish the identity of an organisation, the following two questions are of particular importance:

1. Are we an organisation of *doers* or *thinkers*? In other words, are we in a business of *making* or *doing* things or, are we in a *knowledge* business?
2. Are we offering a *product* or a *capacity* to our customers?

	Doing/making	Thinking/knowing
Product	License Taker	License Giver
Capacity	Jobber	Consultant

Figure I.1 Classification of business identities

The importance of the latter distinction has been stressed by Simon (1980) in his analysis of manufacturing organisations in The Netherlands. The four possible combinations of answers to these questions can be placed in a matrix (Figure I.1). We have labelled the four quadrants:

- License Giver.
- License Taker.
- (High or low technology) Jobber.
- Consultant.

License has to be taken here in the broadest sense of the word. A License Giver may not actually give licenses, or even take licenses on certain components or sub-systems. The essence is that its raison d'être is to generate new knowledge related to a particular product. The classification of Figure I.1 has proven to be useful in discussing not only strategic issues such as design leadership and geographical market penetration, but also the required management profiles, the organisational culture and the requirements that have to be met by the accounting function of a business unit.

Close observation of companies has led me to the conclusion that successful firms tend to fit in just one of the four quadrants or have separated their organisational sub units in such a way that each one fits clearly into only one quadrant. Strategic dilemmas and organisational stress tend to occur when the different characteristics associated with each of the four business identities simultaneously appear within one organisational unit.

We will now explain the nature and describe the characteristics of the four basic identities.

License Giver

Figure I.2 represents the revenues and the costs of a, at that time, market leader in ship engines. The bulk of the revenues came from license fees and only a minor part from own production facilities. The cost price of the engines produced in the corporation's own production facilities is about twice the cost level of its major licensees. Their own production of engines is nevertheless continued because of the need for direct feedback from the field, which is vital to develop the next generation of the product. When the life cycle of the

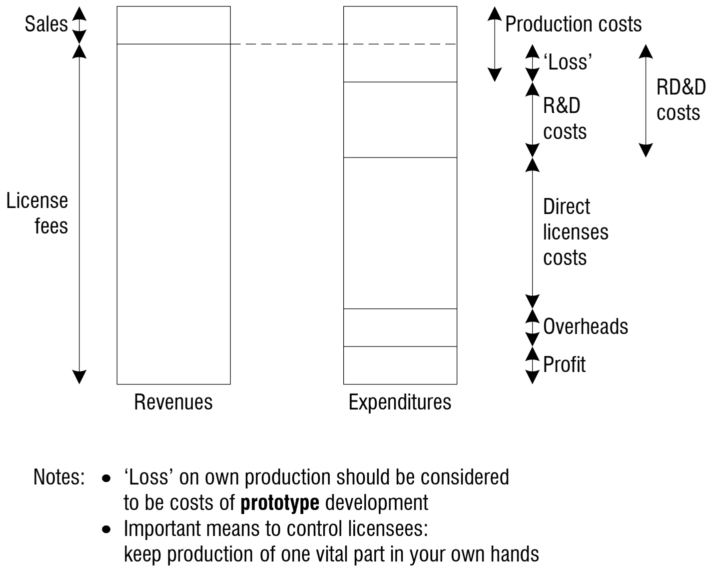


Figure I.2 Annual revenues/costs structure of extreme type of License Giver

current type has expired, the new type should not only incorporate new technologies, which have become available, but should also comply with changes in the requirements by end users. The latter is only possible when continuous feedback from operations is provided. The 'loss' on production should therefore be seen as a special kind of development cost. Together with the R&D costs, they constitute the RD&D cost, i.e. the costs of Research Development and *Demonstration*.

The typical product life cycle (Figure I.3) and the cost of development and demonstration of a new version are determining factors for the annual amount which has to be spent on RD&D in order to remain in the race as a License Giver: the cost to develop a new version and launch it on the market, divided by the typical life cycle (in years) of the product. If we spend less, then we will fall short of critical mass and the new product will arrive on the market too late. This does not imply, of course, that spending the right amount will guarantee success. The R&D expenditures are to be recovered from sales and license fees. As a result, the License Giver break-even point is positioned at a much higher turnover level (in numbers sold or licensed) than in the case of a License Taker (Figure I.4).

When the in-house production becomes small in comparison to the licensed production, the profitability of it becomes of secondary importance. The in-house production is then only maintained as a means to receive direct ope-

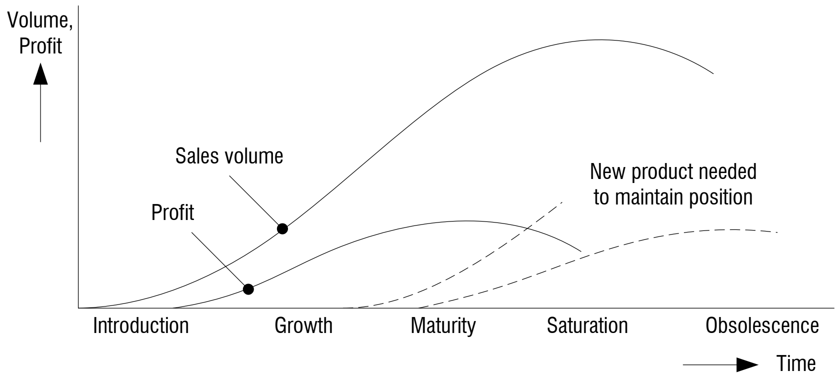


Figure I.3 Product life cycle

rational feedback. The break-even chart of the extreme type of License Giver is shown in Figure I.5.

In short, strategically, the name of the game of the License Giver is to get as many numbers as possible of his product placed on the world market. The typical sequence to achieve this is:

1. Secure home market.

2. Export via agent.

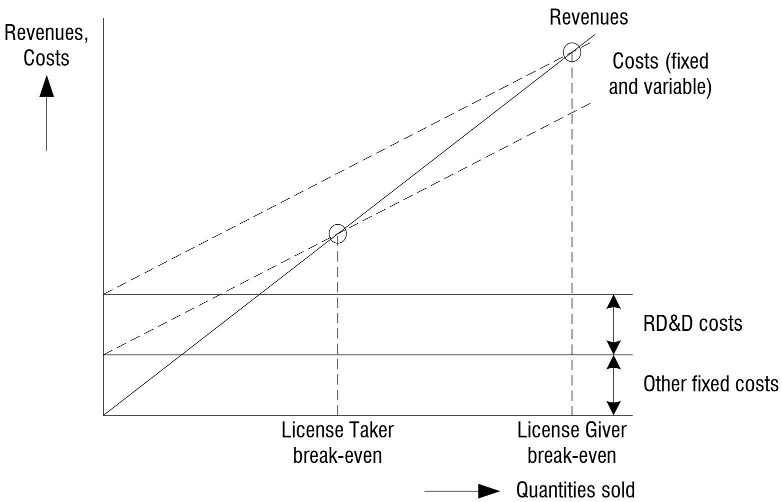
3. Export via local sales office.

4. Form a local joint venture.

5. Arrange a local License Taker (production and sales).

The latter two are necessary to overcome protectionism.

In general, managers of product divisions of a corporation tend to prefer export via agents or sales offices, but are reluctant to engage in joint ventures or full license giving because of the perceived loss of control. From a strategic point of view, however, if the company is not to lose its design leadership, it is essential to make the transition to these stages in time. A powerful means to maintain control over licensees is to exclude one vital (patented) part from the license agreement. The licensee is then forced to purchase that part from the License Giver who thereby keeps in touch with the actions of the licensee in the market. The features of the License Giver are summarised in Table I.1. The emphasis of the License Giver in operations and accounting is summarised in Table I.2.



RD&D costs: Average yearly RD&D (fixed) expenditure to develop a new prototype at a frequency life cycle typical for the product concerned

Figure I.4 Importance of market share to afford R&D

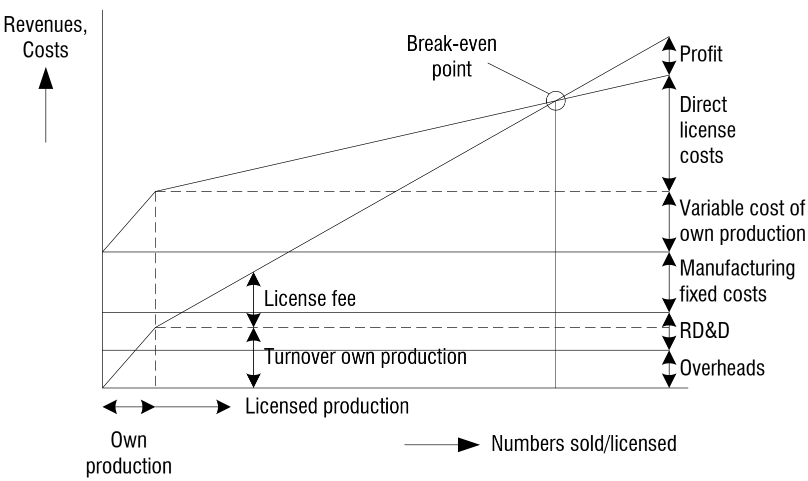


Figure I.5 Break-even chart of extreme type of License Giver

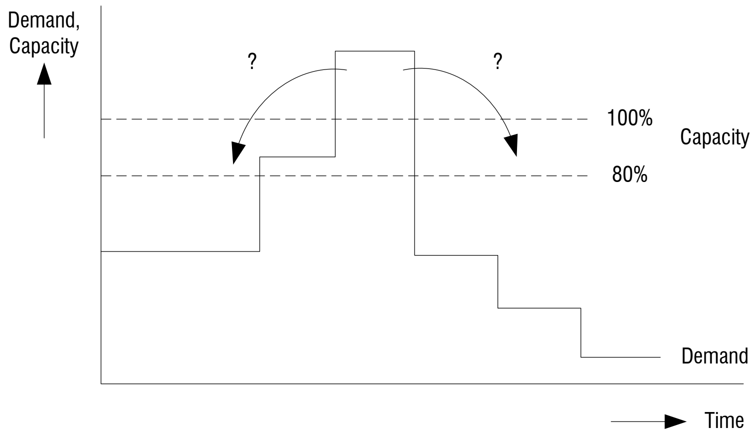


Figure I.6 The levelling problem of the Jobber

License Taker

The License Taker's aim is to exploit the potential of a particular existing product in a limited regional market. The features of the License Taker are summarised in Table I.3. The emphasis of the License Taker in operations and accounting is summarised in Table I.4.

Jobber

The (high or low technology) Jobber offers a multi-functional manufacturing or servicing capacity to the local market. His main concern is to get his capacity utilised to the full (Figure I.6). The features of the Jobber are summarised in Table I.5. The emphasis of the Jobber in operations and accounting is summarised in Table I.6.

Consultant

The Consultant, in this context engineering consultant, hires out his knowledge capacity in a particular field. The features of the Consultant are summarised in Table I.7. The emphasis of the Consultant in operations and accounting is summarised in Table I.8.

The features of the four basic identities are summarised in Table I.9, which shows that they are of a very different nature. As a result, business units adopting strategies belonging to more than one quadrant of the classification of Figure I.1 tend to encounter problems with the consistent pursuance of those

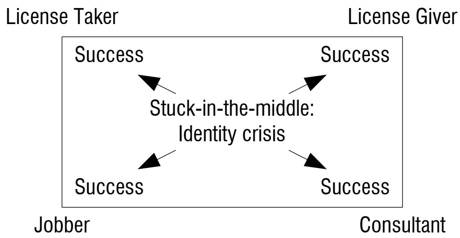


Figure I.7 'Stuck in the Middle' leads to identity crisis

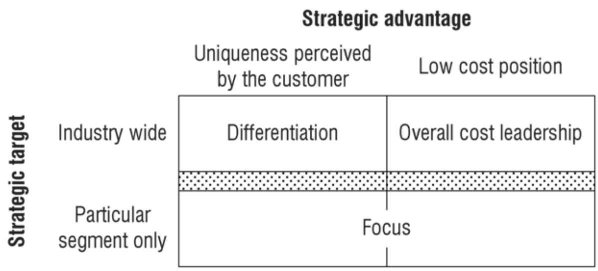


Figure I.8 Generic strategies according to Porter (1980)

strategies. An organisational unit cannot be simultaneously long- and short-term oriented, disciplined and flexible, benefit and cost conscious, etc. The 'Stuck in the Middle' organisation is bound to fail due to a lack of clear identity (Figure I.7).

In his book on competitive strategy, Porter (1980) also warns against a lack of choice between the three generic strategies he defines (Figure I.8). The firm which fails to develop its strategy in at least one of these three directions (a firm which is 'Stuck in the Middle') is in an extremely poor strategic position (Porter, 1980). Porter's generic strategy of Differentiation comes close to the License Giver of our classification but no distinction is made between a product firm and a capacity firm. Although they both may pursue a generic strategy of overall cost leadership, as previously explained, their nature is fundamentally different. The issue of dedicated versus general-purpose facilities is a fundamental one having an impact on almost every aspect of strategic management of a business.

Table I.1 Features of a License Giver

- Key word: Design leadership of a product (worldwide)
- Own production provides operational feedback to develop next generation of product
- High overheads (extensive RD&D)
- In principle, worldwide outlets
- Management orientation focused on:
  - maintaining design leadership (effectiveness rather than efficiency: benefit consciousness rather than cost consciousness)
  - fostering an innovative, entrepreneurial climate
- Sales taken care of at middle management level
- Subcontracting as much as possible
- Financing primarily for new product development and demonstration
- Decision making dominated by long-term strategic considerations
- Short-term pricing decisions heavily influenced by direct costing considerations

Table I.2 Emphasis of a License Giver in operations and accounting

1. Product design
   - estimation of prototype producing costs
   - estimation of market potential
   - establishment of life cycle
   - establishment of schedule for efficient production (for License Taker)
   - estimation, and periodic review resulting in revision of estimates, of standard production costs (also for License Taker)
   - incorporation of (updated) field feed-back into prototype design and (revised) cost estimates
2. Own production
   - scheduling (short assembly time is essential)
   - quality control (if one sub-system fails the whole system fails)
   - cost control with main emphasis on purchasing costs

Table I.3 Features of a License Taker

- Key word: Efficiency
- Outlets in limited regional market (sales and production both local)
- Emphasis of technical development is on process technology (to keep production costs low) and on custom engineering (to adapt the product to local market requirements)
- Moderate overheads (mainly in the area of sales and services)
- Management orientation focused on:
  - regional aspects, for instance relations with key customers, labour unions and local government
  - cost consciousness
- Medium term horizon (moderate risk, moderate profitability)
- Fostering thoroughness and discipline
- Sales taken care of at middle management level
- Subcontracting as much as possible
- Financing primarily needed for replacement and extension of production facilities (tailored to product)
- Short-term pricing decisions heavily influenced by local market conditions
- Emphasis in accounting on purchasing (goods and services)

Table I.4 Emphasis of a License Taker in operations and accounting

1. Purchasing on call orders
2. Production for inventory (large series)
   - scheduling geared to maximum efficiency
   - cost control through standard costs with variance analysis
   - inventory cost control
   - cost control of work force (shifts)
3. Production on customer orders (small numbers)
   - critical path analysis to meet delivery time
   - overall cost control through project cost control (cost estimate – progress – estimate to complete – alternative critical path – revised estimate – etc.)
   - squeeze on his ‘Technology Jobber’ (sub-supplier)
   - control on efficiency per department by standard departmental shop floor cost (variance analysis)
   - control on material cost by competitive bids governed by quality specifications and track record of timely delivery (reliability reputation of sub-supplier)

Table I.5 Features of a Jobber

- Key word: Occupancy of multi-functional utility (general purpose facility)
- Outlets regionally limited by tariff barriers and transportation costs
- Emphasis of development, if any, on process technology
- Low overheads
- Management orientation focused on:
  - plant occupancy
  - cost consciousness
  - short-term horizon
  - flexibility and labour motivation ('we'll fix it' mentality)
- Sales taken care of at highest management level (knowledge about deadline exposures of current and potential customers)
- Subcontracting as little as possible
- Financing primarily needed for replacement and extension of production facilities (general purpose)
- Decision making, including short-term pricing policies, dominated by planning of plant utilisation

Table I.6 Emphasis of a Jobber in operations and accounting

1. Emphasis on capacity efficiency; accounting system should provide the basis for discounts to customers for rescheduling (disproportion in area above 80% should be readjusted by means of discount and extra charges, see figure I.6)
2. Post-mortem review to establish unit or job cost
3. Where 'main-supplier': control on job cost by exploiting learning curve
4. Control on efficiency per department by standard departmental shop floor cost (variance analysis)

Table I.7 Features of a Consultant

- Key word: Customer service
- Hiring out of knowledge capacity
- Emphasis of development activities: incorporation of new techniques in procedures and programmes
- Low front investments
- Low overheads
- Management orientation focused on:
  - selling man-hours, mainly with a short-term horizon
  - productivity
  - development of consultant's skill (to maintain level of knowledge)
- Selling at all levels, however main sales taken care of at highest management level
- Subcontracting as little as possible
- Decision making tends to be opportunistic

Table I.8 Emphasis of a Consultant in operations and accounting

- Utilisation of available hours (minimum 75% of 1500 hours per annum per person)
- Budgeted man-hours versus actual
- Stringent cost control on overheads
- Budgeted training costs as a percentage of standard per diem rates
- Stringent cost control on out-of-pocket expenses (authorisation at highest management level)

Table I.9 Comparison of basic identity characteristics

	License Giver	License Taker	Jobber	Consultant
Name of the game	Largest possible number on the world market	Capture of regional market by favourable price / performance ratio	Plant occupancy	Utilisation of (knowledge) man-power
R&D emphasis	Product design leadership	Process technology	Custom engineering	Adapting available techniques to customer needs
Time horizon	Long term	Medium term	Short term	Short term
Geographical focus	World	Country	Local	Local
Organisational climate	Innovative, Entrepreneu-rial	Discipline	Flexibility, labour motivation	Opportunistic
Cost emphasis	Effectiveness, Benefit consciousness	Efficiency, Cost consciousness	Cost consciousness	Out-of-pocket expenses and overheads
Overheads	High	Moderate	Low	Low
Sales	At middle management level	At middle management level	At first management level	At all management levels
Subcontracting	As much as possible	As much as possible	As little as possible	As little as possible
Main thrust of investments	RD&D	Dedicated plant	General purpose equipment	Training

I.3 The multi-business corporation

The basic identities can flourish alongside each other within one corporation, as long as the associated organisational units are kept separate and their autonomy is sufficient to allow them to develop their own appropriate approach to business problems (along with a general corporate spirit). Conversely, when the identities are mixed up in one organisational unit, a split-up will resolve most of the prevailing organisational dilemmas. Such a split introduces the problem of intra-corporate deliveries. More often than not, we see that one unit is either obliged to purchase from the sister unit or to give it at least the right of first refusal. This is a misleading concept, which should be avoided. Third parties will very soon find out that they are only used as a price leverage to bring the sister unit to a lower price but that they never get any orders.

The result is that they do not make a serious offer or they straightforwardly ask the sister unit what price they should quote and the whole procedure becomes a ritual. An effective means to induce genuine competition without having the well-known drawbacks of general comparative shopping is the concept of the second main supplier. For each strategically important purchasing segment a firm should see to it that it gets (at least) two main suppliers. The second main supplier should get, over a longer period of time, at least 30%, the first one a maximum of 70% of the relevant purchasing segment. This means that the second main supplier should temporarily get a right of first refusal whenever the balance has to be restored. In this way both suppliers will remain alert, which is not only in the interest of the purchasing unit but will also improve competitive strength of the suppliers (including the sister unit) in the open market.

I.4 Discussion of four typical cases

Let us now return to the four cases cited at the beginning of this section and see how they fit in our classification.

Case 1:

Division A producing gas turbines according to their own design, is a clear-cut case of a License Giver. A major part of the corporation however, could be characterised as a (high technology) Jobber that apparently heavily influenced the decision-making by corporate management. Post-mortem analysis of the key order concerned revealed the following:

- *Plant utilisation,* i.e. the key issue of the Jobber, was a major consideration in top management decision-making.

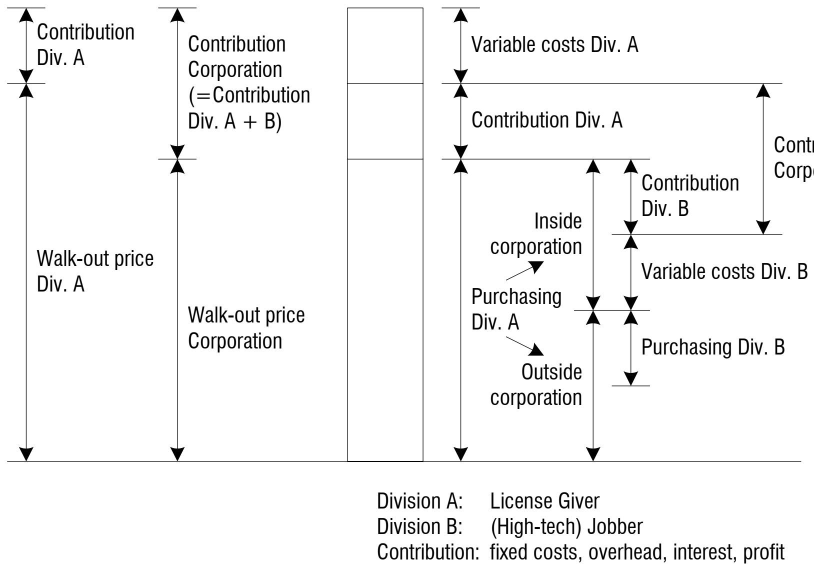


Figure I.9 Walk-out price can significantly be affected by inter-divisional deliveries

- The 'walk out' price that corporate management had in mind was entirely based on the contribution that would be generated in Division A. That a substantial contribution to overheads would be realised in Division B was completely overlooked as a result of insufficient insight into the *transfer pricing procedures* (Figure I.9).

- Letting this key order go to the competition actually meant ceasing to be a real *License Giver*. This fact was only realised a considerable time after the decision had been taken. As a result commensurate measures to cope with it were taken at a slow, and heavily loss making, pace.

Case 2:

Division X, being licensee for three different designs in addition to development efforts related to an own design, was actually in a 'Stuck in the Middle' position between License Taker and License Giver. Break-even analysis (Figure I.4) revealed that the company either had to return to its position as a pure License Taker, or complete its transition towards a position of License

Giver.* To achieve the latter, the turnover in terms of numbers (of controllable pitch propeller installations of own design) had to be doubled. A marketing strategy to this end was devised and implemented. The turnover was doubled in two years. The marketing strategy included the following features:

1. Stressing *reliability* of the (own) design. Reliability of the propeller is directly related to the availability of the whole ship is, and therefore, the *key selling function*.

2. Directing marketing efforts towards ship owners, i.e. the *end users*, rather than towards shipyards.

3. Using the concept of *nuisance value* vis-à-vis the main competitor, i.e. displaying marketing efforts in his home market. Consequently, if the competitor wished to maintain the price levels in his home market he had to respect price levels in those geographical areas where Division X was strong and in a position to increase market share.

4. Regionally *differentiated price levels*.

5. Progressive and regionally *differentiated commissions* to agents.

In this way, the Division definitely succeeded in establishing itself as License Giver and became the main profit maker of the corporation.

Case 3:

As Division P originated from a workshop for the installation division it possessed the typical features of a Jobber. Its manager however, wishing to make the Division a manufacturer in its own right, emphasised the development of own products. That is to say, in words and not in behaviour, which remained focused on satisfying the short-term needs of customers the manager happened to be in contact with. The short-term problems always took precedence over the long-term opportunities. As a result, jobbing work remained the main source of income but was not sufficient to compensate for the substantial losses on the own products. A strategy to return to a pure Jobber status was therefore adopted and profitability was gradually restored.

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*Although the option of returning to the position of a pure License Taker was undoubtedly the best option from a financial point of view, it was rejected straight away by the CEO (and owner) of the company as well as by the dominant coalition of engineers (including the author) simply because it was not in line with their personal ambitions.

Case 4:

The apparatus for sub sea soil investigation had the potential of entering the market of sub sea equipment as a License Giver. Entrusting its commercialisation to an Engineering Consultant made this no longer possible. The management used its unique selling points to sell engineering hours and thereby failed to exploit its longer-term potential by sustained development of a Mark II and III. From their point of view as a Consultant this was perfectly in order, but the key people involved in the development left to join License Giver type companies in sub-sea equipment.

I.5 Practical implications

To summarise, adopting a strategy for R&D should imply a choice that should be in line with the existing identity of the organisation. The choice should be deliberate and not merely going for the only remaining option. An R&D strategy not only implies a choice as to what to pursue but also as to what not to do. When these points are neglected, R&D output cannot be properly commercialised or it will lack critical mass as a result of splintered effort. In practice this includes four distinct steps:

1. Analyse the history of the firm in terms of its realised strategy, i.e. what was actually done. This allows characterisation of the way of thinking of the dominant coalition of the firm in terms of License Giver, License Taker, Jobber or Consultant.

2. Identify activities that do not fit in the business identity of the dominant coalition as found in step 1.

3. Revise the organisational structure in the sense that the activities identified in step 2 are separated into units having a specific character according to one of the four basic business identities. Sufficient autonomy must be given to these units to allow them to develop their own style of doing business that will necessarily be different from that of the dominant coalition.

4. Let the business units as defined in steps 1 and 3 develop their own business strategy.

   Example: *Publisher-printer firm*

   A firm engaged in both publishing and printing with these activities organised in a highly intertwined way found itself in a continuous loss-making situation. The publishing part of the organisation was held responsible for this; the common opinion in the company was that the book titles were not of sufficient quality to be attractive to the public. According to our strategic classification, a publishing business is a License Giver, whereas a printing business is a Jobber.

Reorganisation was therefore carried out which was directed to separating the firm in two fairly autonomous units. The publishing unit was organised in line with the typical License Giver characteristics. Contrary to past practice, it was allowed to have the books printed by third parties. The printing unit was organised in line with the typical Jobber characteristics. The utilisation of its capacity was made their own responsibility in the sense that they had to regard the publishing unit as one of their customers and no longer as a scapegoat for their own problems. As a result buck-passing and internal quarrelling came to an end and profitability was restored.

II Information handling

Information technologies not only offer great opportunities, but also confront the manager or knowledge worker with a problem, namely, *how to cope with the ever-increasing overabundance of information.*

My approach to this issue is summarised in this Appendix, as published in Van Gunsteren (1988), because it can help the reader to identify what information, in his particular situation, is relevant for adequate engineering design and execution.

II.1 A typology of information

Let us consider the case of a manager who has to make a decision. If God himself were to make that decision, He could make use of all the information relevant to the matter concerned. This information is labeled *relevant information* (Figure II.1).

The manager, of course, receives much more information than he is ever able to use for his particular decision. This information is labeled *information paid attention to*. The part of that information that has relevance to the purpose concerned - the decision to be taken - is called *used information*.

Relevant information to which no attention is paid, is labeled *Cassandra information*. The god Apollo, being in love with Cassandra, the beautiful daughter of King Priamus of Troy, gave her a present: the ability to predict the future. When she rejected him in spite of that gift, he could not take it back because a gift from a god is a gift forever. Therefore, he provided her with another: no one would ever listen to her. When she warned the Trojans about the wooden horse, her advice was ignored and the city was subsequently destroyed.

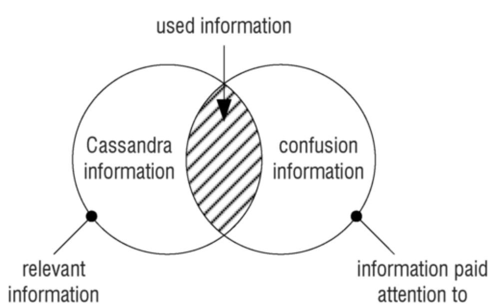

Figure II.1 Information pertinent to managers.

The reason why available relevant information is ignored, is often its threatening nature. For the Trojans the information that the terrible war with the Greeks was not over, was simply too threatening. Other causes are:

- Poor accessibility.
- Filtering information to avoid ambiguity as described in Section 6.2.

The information paid attention to by the manager that is not relevant is called *confusion information*, as this type of information tends to confuse the issue. In dealing with information, the manager should, of course, primarily be concerned with Cassandra information. He must strive to reduce the likelihood that relevant information is overlooked or ignored.

In principle, this can be done in two different ways (Figure II.2):

- Increasing the information paid attention to. It cannot be denied that in this way Cassandra information is indeed reduced, but at the same time confusion information increases. The availability of ever more powerful computers generates a trend in this direction (making the problem of overabundance of information worse than it was already);
- Reducing Cassandra information along with reducing confusion information. This is what good (expert) consultants try to do: telling their client what is relevant to him. No more, no less.

The latter is the essence of our typology: try to simultaneously minimize both Cassandra information and confusion information.

II.2 Filtering information to avoid ambiguity

It is human nature to dislike ambiguity and indecisiveness. As a result, people have difficulty to change their view once they have formed their opinion.

Their apparent unwillingness to face reality in the light of new information should not be seen as dishonesty. Their perception may be genuine but distorted by a process of selective filtering of information, which tends to confirm the correctness of their point-of-view or the decision taken. This phenomenon, known as *cognitive dissonance reduction*, is explained by Festinger's theory of cognitive dissonance (1957), which can be summarized as follows. A person who has to choose between two alternatives, experiences an uneasy feeling, *cognitive dissonance*. This uneasiness is stronger:

- The more the perceived advantages and disadvantages of the two alternatives are in balance.

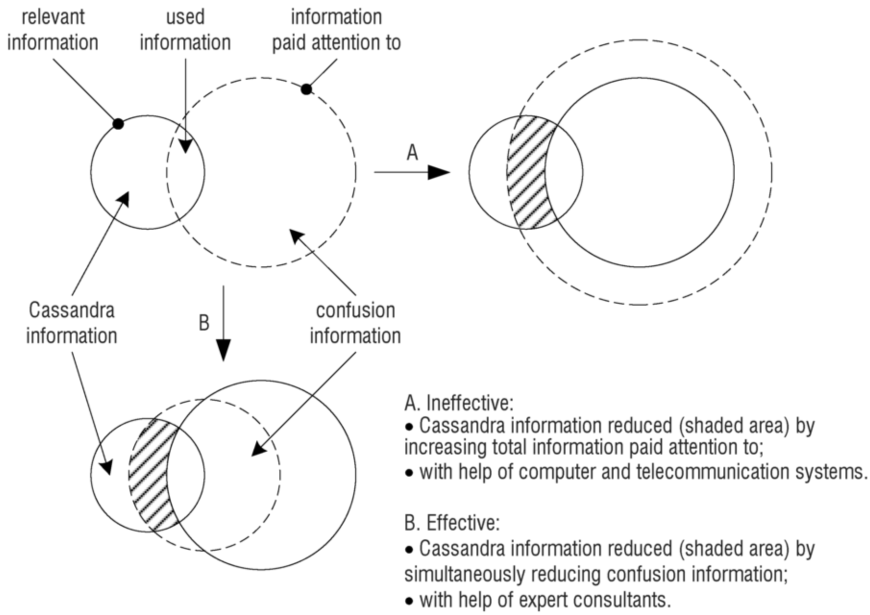

Figure II.2 Two approaches to reducing Cassandra information.

- The more important the matter is (e.g. to decide on another job causes more cognitive dissonance than the decision on bringing along an umbrella since it may rain or the weather may be fine).

The cognitive dissonance does not immediately disappear once the person has made up his mind. To reduce it, the person selectively absorbs information which confirms the decision made, the phenomenon of *cognitive dissonance reduction*. It explains why brochures on cars are not primarily collected by people who intend to buy a car, but by those who have just bought one! It explains why a board of directors is always reluctant to fire a managing director they once appointed. Similarly, when an operation gets the green light, the information paid attention to by the decision makers is invariably of a positive nature, making it extremely difficult to accept, at a later stage when new relevant information surfaces, the conclusion that it should be abandoned. Operation Market Garden in WWII in which the information on the presence of two SS armor divisions near Arnhem was ignored by Montgomery's staff, is a tragic example.

When deliberations on a decision continue over a long period of time, the acceptance of the decision, either way, is reduced as a result of the cognitive dissonance reduction of the players involved. Awareness of the phenomenon of cognitive dissonance reduction and realization that no human being can escape its effects, can help to achieve appropriate timing of decisions.

II.3 Managerial effectiveness in handling information

In practice, we often see that managers tend to swallow whatever information reaches them (approach A of Figure II.2). They read almost everything that arrives on their desk and attend seminars on a variety of subjects, and still their curiosity seems never to be satisfied. In their day-to-day decision-making they ask first what information is available and only secondarily what is relevant. In this way a lot of information paid attention to is confusion information which can have a paralyzing effect on the manager. This approach is, therefore, ineffective.

Effective managers place primary emphasis on what is relevant before looking at what information is available (Table II.1).

Relevant information that cannot be obtained is taken into account by analyzing the implications of the manager's options in various scenarios. A scenario is a relevant and plausible future that cannot be controlled. A strategy is an option, a choice of a course of action, available to the decision maker.

Let us explain the concept with the example of the decision on a holiday destination. When the weather is bad, you want to visit a museum or attend a concert. When the weather is fine, you want to sport in the fresh air. But you don't know, and never will know, what the weather actually will be. Your options and their consequences in the bad-weather scenario and in the fine-weather scenario are given in Table II.2.

You decide for option C and are prepared to pay the higher hotel price to be sure of a good holiday regardless of the weather. This is the essence of scenario planning: create, with imagination and fantasy, a strategy (option) yielding a satisfactory outcome in various scenarios.

For an airline, the decision to expand or to consolidate depends on the future demand of passenger airmiles. The scenario planning for this dilemma could be as given in Table II.3.

Scenario planning has become fashionable after its successful application on a global scale by Shell. As a result, the technique tends to be associated with large organizations. The underlying principle, however, of accepting that certain relevant information simply cannot be obtained, but can nevertheless be accounted for in strategic decision making, is by no means limited to large corporations (as is illustrated in our holiday example).

Table II.1 Effective managerial approach to cope with information

Sequence:
What is relevant to my purpose?
What is available?
What is still missing?
Assumptions on relevant information that cannot be obtained.

Table II.2 Scenario planning for a holiday

	Scenario: Weather	
Strategy	fine	bad
A. Resort for outdoor sports	++	−−
B. Resort for cultural activities	−−	++
C. Resort offering both (hotel being 10% more expensive)	+	+

Table II.3 Scenario planning for an airline

	Scenario: Passenger air mile demand	
Strategy	low	high
A. Expand: buy planes, hire pilots	−−	++
B. Consolidate: do not invest in airplanes and pilots	++	−−
C. Buy options for airplanes, offer pilots the option of a contract which provides them with a bonus for the employer's right to fire them when necessary.	+	+

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Index

About the Author

Lex A. van Gunsteren (1938) is a business consultant, lecturer and innovator in marine propulsion. He graduated as a naval architect and received his PhD from Delft University of Technology, where in 1981 he was also appointed as Professor in Management of Technological Innovation. He was one of the pioneers of the Rotterdam School of Management where he taught management of innovation and crisis management.

After his military service as an officer in the ship design unit of the Royal Netherlands Navy, Lips Propeller Works employed him, initially as an industrial scientist and later in various managerial positions. In the shipbuilding group IHC Holland, he was managing director of their shipyard Gusto, specialised in off shore equipment. In the Royal Boskalis Westminster Group, he served as director of corporate planning and R&D. In the late eighties, he founded the innovation company Van Gunsteren & Gelling Marine Propulsion Development for the further development of his invention of the slotted nozzle (duct with a slot at the front), which ultimately led to the successful application of the wing nozzle (duct with a slot at the rear). He served on various boards for monitoring R&D subsidies, among others as vice chairman of the board of the Dutch Foundation for Technical Sciences 'STW'.

Currently, he lectures Stakeholder-oriented Project Management at the Faculty of Civil Engineering and Geosciences of Delft University of Technology. His publications include six patents and ten books.