Space Research Project Management Can Benefit from Engineering Technology Selection Methods

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Abstract

Many engineering methods have been developed to help management select technology for a system design or further research. The simplest way to compare technologies is to use a checklist containing all the more or less important selection criteria, so that nothing is overlooked. The criteria usually include cost, safety, reliability and maintainability, and potential problems such as noise generation and microgravity sensitivity. The next step typically is to weight and score all the criteria. The process of weighting and scoring is helpful in bringing out different priorities and reaching a shared point of view. Group technology selection methods are designed to highlight initial disagreements and produce a shared consensus. Often a frank discussion led by management rather than decision analysts can be more effective. The final selection depends on management and engineering judgment and may include programmatic and organizational factors that are beyond the engineering checklist. The objective of engineering technology selection methods is to provide engineering information to assist management in making sound decisions.

Project management and technology selection are assumed to use rational engineering analytic methods, but they often do not. The reason is that human insight, intuition, and "gut feel," rather than logic, more frequently determine our decisions. Project selection and management are strongly influenced by nonrational psychological influences, which can produce unjustified confidence and determination.

Nevertheless, there is a strong need for space projects to do rational project analysis and selection. Demonstrating a rational spirit is necessary for a scientific and technical organization. Professional ethics at its best requires an open, honest, and fair process, without damaging politics. Rational analysis can help improve good projects and avoid selecting bad ones. A sanity check using rational analysis guided by a checklist can help avoid egregious and damaging errors.

Keywords: (project selection, checklists, engineering judgment, intuition, gut feel, nonrational decisions)

Acronyms

ESM =	Equivalent System Mass
LCC =	Life Cycle Cost
NPD =	New Product Development
NPV =	Net Present Value
Pr(LOC) =	Probability of Loss of Crew
R&D =	Research and Development
TRL =	Technology Readiness Level
WYSIATI =	What You See Is All There Is

1. Introduction

Space projects are usually supported and approved based on management judgment and the organizational budget process. The project selection process should also include an engineering technology selection method, such as using a checklist of criteria. This can help prevent the approval of seriously flawed project.

2. Engineering methods to select technology

This section describes technology selection using checklists and mentions some other analytic and quantitative methods. A radar chart can be used to display the criteria on the checklist.

2.1 Checklists

Checklists are a simple way to identify the relevant factors in making a technology selection decision. Neglecting an important systems engineering consideration such as risk can be very harmful.

2.2 Space project selection criteria

A new space technology should not be selected for flight unless it meets the well-known criteria of safety, availability, performance, and cost. Safety appears to be most important in selection, availability next, then performance, and cost appears least important. But any single criterion can be the deciding factor. A candidate technology can be rejected because of deficiencies in safety, availability, performance, or cost. And other things being equal, a technology can be adopted because of clear superiority in only one of the selection factors.

Safety is the most important technology selection determinant. The safety requirement for manned space systems has traditionally been that there are no single point failures that could result in injury, loss of life, or loss of mission. This has led to the use of redundancy, such as the common requirement for two fault tolerance. A better measure of safety is the probability of loss of crew, Pr(LOC), since in some cases adding redundancy can actually increase the probability of loss of crew. Normally a candidate flight system will be designed to meet the required probability of loss of crew, and this will impact cost and performance. Hazards should be identified, including high temperature, high pressure, high voltage, high power, and dangerous materials.

The availability of hardware for space flight is usually measured by its Technology Readiness Level (TRL). TRL appears to be a governing factor in space system hardware selection, for several reasons. A technology with a TRL of less than 5, meaning validated in a relevant environment, is not usually considered in flight system selection. The TRLs of candidate technologies increase when more R&D is funded. Since continued investments would be directed toward technologies promising better safety, performance, or cost, a high TRL suggests that these other criteria will also be high. Higher TRL usually implies that the remaining development cost will be lower.

A candidate flight system will be designed to meet all the functional performance specifications, including operations, interfaces, and quality. Some other aspects of performance are microgravity sensitivity, contamination potential, noise level, flexibility in use, and commonality of application. The "-ilities," operability, maintainability, and reliability, impact the required crew time and the operations costs. Complexity is difficult to quantify but seems related to more difficult maintenance and repair and more time consuming operations. System complexity is recognized as a cost driver in some cost estimation methods.

Life Cycle Cost (LCC) is a basic metric in systems analysis and project selection. LCC combines all the costs of a mission in one number. These costs include system development and test, supporting equipment, space launch, resupply, operations, maintenance, and even decommissioning. Higher LCC may be justified to obtain better safety and performance. If other criteria are nearly equal, mission designers would tend to select the system with the lowest LCC.

Future costs should be discounted to their net present value (NPV). Since money earns interest, a dollar now is worth more than a dollar later. Economic theory also states that past costs are not relevant to current system selection. Past investments are sunk costs and cannot be recovered. The current situation, not past actions, should determine current technology choices.

2.3 Radar chart display of the criteria scores

The radar chart can be used to display the multiple criteria used in a technology selection process. The radar chart can easily display two or three different systems described by five or more criteria. Compound criteria such as performance and cost can be split into factors that are displayed in lower level radar charts.

The numerical estimates for probability of loss of crew, TRL, and LCC, and the qualitative scores for performance and the 'ilities must be converted to criteria scores for display in a radar chart. Higher positive scores indicate better performance and the highest possible scores should be equal if we want to give equal weighting to the criteria. A smaller Pr(LOC) is better, so higher numbers get lower scores. Safety score = 100*lowest Pr(LOC)/scored system Pr(LOC). Higher TRL is better and the maximum TRL of 9 of should correspond to a score of 100. Better performance and 'ilities get higher scores, with best performance getting the maximum of 100. Since lower LCC is better, like lower Pr(LOC) is better, a similar inverse metric is needed. LCC score = 100*lowest LCC/scored system LCC.

Table 1 gives example criteria scores for two Projects, 1 and 2.

Table 1. Criteria scores for Project 1 and Project 2.

categories	Project 1	Project 2	Project 1 - Project 2
Safety	100	60	40
TRL	40	50	-10
Performance	60	80	-20
'ilities	80	55	25
LCC	85	100	-15
Sum of scores	365	345	20

Figure 1 shows the radar chart plot of the scores in Table 1. If the data category number scales accurately reflect the relative values of the categories, the best system choice is the one with the greatest sum of the category data values. Project 1 has a sum of 365, Project 2 of 345, a difference of 20. It is probably better to select a project based on an overall impression and the decision maker's valuation of the criteria than on the specific scores. Selecting Project 1 would provide strong advantages in safety and the 'ilities,, but accept lower TRL, lower performance, and higher LCC.

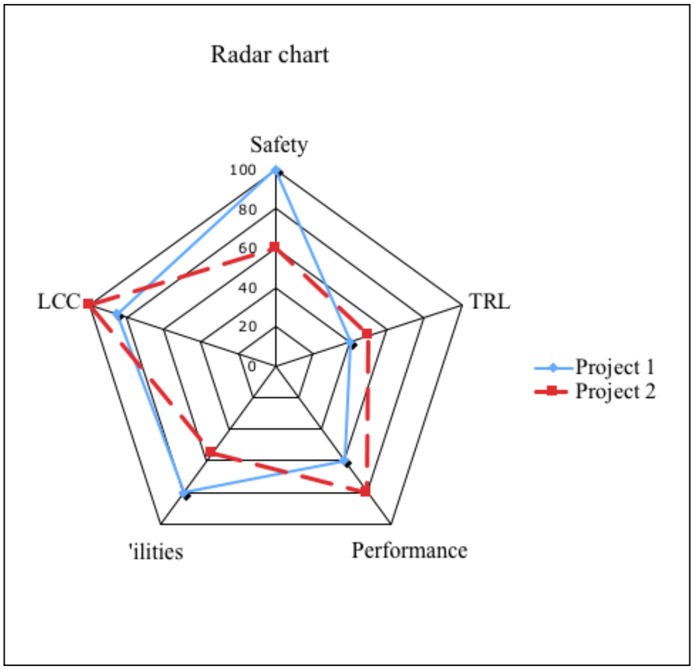

Figure 1. Radar chart comparing Projects 1 and 2.

2.4 Project selection errors

Common project selection analysis errors include:

1. Missing criteria
2. Dependent or correlated criteria
3. Ignored good alternative project choices
4. Different criteria used for different projects
5. Wrong decision maker or stakeholders
6. Predetermined or biased decisions
7. Undocumented rationales for criteria, weighting, scoring, and selection

2.5 Other analytic and quantitative methods

A survey of 200 US technology R&D organizations concluded that those R&D organizations were satisfied with their project selection approach, if it used an open formal process, that included several techniques, that was applied to all projects at the same time, and was supported by management. The more popular methods were Net Present Value (NPV) (used by 77%), resource allocation by strategic goals (65%), scoring (38%), checklists (21%), and scatter diagrams (41%). All the organizations used more than one project selection method and the probabilities add to 242%, so 2.4 was the average number of methods used. NPV depends on future financial projections and was considered less helpful. [1] Strategic goals are important but lie outside of the project itself. Checklists and scoring seem direct and useful. The radar chart can show many more than the two dimensions shown in a scatter chart.

2.5 Non quantitative project success factors

Different success prediction factors are important in the two basic different types of projects, R&D and New Product Development (NPD). For R&D, high level management support, the probability of technical success, an existing customer, and the need for lower cost are the major success factors. For NPD, good planning, strong marketing, and a favorable competitive environment are more important. However, management support and customer commitment often depend on expected technical success, so a high probability of success is usually needed for project approval. [2]

2.5 Formal group project selection

Organizations that are satisfied with their project selection approach typically use group discussion methods with clear rules and procedures that are applied to all projects at the same time. Their project selection process is strongly supported by management. This helps to build consensus and develop management insight. It encourages better project proposals by clarifying the desired project attributes. It gains rank-and-file support by appearing fair. [1]

A good project selection process should do the following:

1. Evaluate all the proposals
2. Use the same criteria
3. At the same time
4. Rank the proposals and have everyone understand the ranking
5. Select a balanced portfolio according to understood objectives

3. Formal project selection is not widely used

Many different technology ranking and project selection methods have been proposed, but they have had poor acceptance and questionable effectiveness when used. "Although the published literature over the past 30 years outlines many approaches for portfolio management and project selection, there is very little evidence regarding the widespread transfer of these techniques into management practice or whether these approaches have had positive results." [1] "Classical R&D project selection models have been virtually ignored by industry." [3]

3.1 No proven good methods

The primary reason for the limited use of formal project selection methods is that there are no universally accepted, no proven good methods. "Contrary to the belief of many people, there are no significant data or empirical evidence upon which to base a more rational approach to research management. … no reliable data exist on the effectiveness of the quantitative methodologies … R&D managers have chosen, generally for good reason, to retain personal responsibility for project evaluation." [4] Some researchers have concluded that there are no project criteria that have been proven useful in selecting better projects. "Researchers have been unable to converge on any key success factors." [5]

3.2 Use of more intuitive group methods

The early hope that project selection could be done solely by formal objective mathematical methods has been replaced by more acceptance of an inevitable subjective group process. Currently technology ranking and project selection use simple and intuitive methods, such as scoring using a list of criteria, group consensus, and consideration of strategic balance. These are user-friendly and more suitable for existing groups within organizations than for single decision makers. [1]

4. Intuition is the key factor in project selection

It has long been realized that, "Intuition is important in most management decisions." [4] "(L)arge elements of judgment, intuition, and experience characterize management decisions." [6] "Many of the decisions in R&D are still made based on ad hoc methods of 'gut feeling'." [7]

"Prevailing mythology depicts managers as rational … it's wrong." When this is pointed out, "they always respond with a mix of discomfiture and recognition. … they don't like to be told about it. …rationality (is) an afterthought." [8]

5. Human intuitive heuristics

In Daniel Kahneman's book, *Thinking, Fast and Slow*, he explains there are two types of human thinking, fast, intuitive, emotional or, in contrast, slow, deliberative and logical. [9] Kahneman won the Nobel prize in economics for experiments disproving the common assumption that humans were rational economic optimizers and by explaining the human decision errors that are common in intuitive thinking.

Kahneman labeled the two complementary decision making systems as System 1 and System 2. System 1 is associative, holistic, subconscious, automatic, easy, and fast. It is used for quick response in familiar situations and includes many common decision biases and heuristics. It is usually considered partly innate or hard wired, primitive, and inferior to System 2. System 2 is analytic, controlled, conscious, logical, difficult, and slow. It is used to consider complex social and technical problems and often uses mathematics, logic, and science. System 2 is learned through culture and formal teaching and is expected to be revised based on reason and evidence. [9]

The heuristics described by Kahneman include anchoring, attribute substitution, availability, framing, loss aversion, overconfidence, and the sunk cost fallacy, all of which can strongly bias decision making.

Three human heuristics that particularly affect project selection are loss aversion, myopia, and inside view overconfidence. Loss aversion refers to the fact that losses are felt much more strongly than gains of the same objective cash value. People will risk gambling gains, "house money," more readily than their own funds. Myopia refers to valuing near term gains much more than long term gains. People often prefer taking $100 now to $120 in a year, implying that their required interest rate is more than 20%. Inside view overconfidence refers to the fact that people consider the chance of success in their own projects, that they know from the inside, much higher than the statistical average chance of success of unknown projects. These heuristics are not economically rational in the modern world, but they seem to have been practically useful in the evolutionary past.

5.1 Individual heuristics affect project selection

Organizational project selection seems to be impaired by these individual human heuristics. Because of loss aversion and myopia, an organization will "turn down a series of risky projects, fearing potential losses, even though portfolios of such projects appear acceptable." Due to myopia, organizations "choose projects one at a time, rather than considering portfolios of projects." Overconfidence based on the inside view "may be the main reason that myopic, loss-adverse managers take any risks at all." [10]

5.2 Sunk cost fallacy?

One common recommendation in economic decision making is to ignore sunk costs, which are all the past and unrecoverable expenditures. Projects should be selected by considering only the future costs and benefits. MBA students and others educated in economic decision making are compellingly trained to "ignore sunk costs." But this defines them as members of "a minor subculture," since "to one not versed in these matters, the phrase is cryptic and the concept is not natural." [11]

Sunk costs are rarely ignored in the real world. Projects are pursued long after they get in trouble and the original expectations are obviously unlikely to be met. Failing projects are funded and often have their funding increased rather than cut because of personal investment and public commitment to the project. [12] Large overruns, schedule delays, and performance shortfalls become routine.

5.3 The group can correct individual errors?

Somewhat surprisingly, Kahneman, who disproved rational economic man, has great hope for the rational organization. "Organizations are better than individuals when it comes to avoiding errors, because they naturally think more slowly and have the power to impose orderly procedures. … an organization is a factory that manufactures judgments and decisions. Every factory must have ways to ensure the quality of its products (i.e., decisions)." [9] Rational organizational behaviour remains an idealistic hope to be achieved.

5.4 Overconfidence due to WYSIATI

The lack of technical analysis in project selection is a sign of overconfidence. Kahneman explains overconfidence as, "Jumping to conclusions on the basis of limited evidence." To refer to this phenomenon throughout his book, he creates the acronym, WYSIATI, What You See Is All There Is. Quick intuitive thinking "is radically insensitive to both the quality and the quantity of information that gives rise to impressions and intuitions." WYSIATI ignores information, and limited reality testing is the root cause of overconfidence. WYSIATI "facilitates the achievement of coherence and of the cognitive ease that causes us to accept a statement as true." [9] Good project selection would avoid WYSIATI and attempt to gather and weigh all relevant information. Using a checklist can draw attention to things we do not see here and now.

6. Intuition can lead to good decisions

It has been usual to prefer and advocate the use of rational analysis as in Kahneman's System 2 for management and technical problems, but recently the intuition of System 1 has become more appreciated. In addition to quick judgments in simple situations, such as same or different, gain or loss, friend or foe, intuition also includes pattern recognition and reaction to learned complex patterns, such as chess positions or social situations. People learn to recognize complex situations unconsciously and can develop strong emotionally felt reactions to them that they cannot readily explain. A person who has dealt effectively with similar situations for many years will develop a subject area expertise and trained judgment that can produce highly effective intuitive decisions. Competent respected top managers often lead very successfully simply by following their gut.

6.1 Support for using insight

Advances in social psychology and neuroscience have helped explain the use of intuition in organization management. Decision science researchers have made progress in understanding non-conscious ways of knowing, including distinguishing between instinct, intuition, and insight. Most decisions seem to depend more on emerging feelings based on gut feel than on explicit conscious reasoning processes.

Advocates of using intuitive management judgment based on deep experience have claimed that intuition "is an indispensable component of strategic competence" and "is as essential to the competence portfolio of hard-pressed decision makers as many of the analytical skills that feature in contemporary business school curricula." [13]

Intuition is a judgment about a possible course of action that comes to mind with a feeling of rightness, but without the ability to provide clear reasons or justifications. We know what to do but we can't explain why it's right or how we discovered it. Intuition should be checked against reality, hard facts, and logical inference. Correct intuition and sound rational analysis should give the same answer. System 1 and System 2 are best thought of as two parallel systems of knowing. When intuition and reason disagree, it is often because intuition includes subconscious factors not accessible to reason, suggesting that rational analysis needs further effort. The strong conviction produced by intuition explains why it often dominates and distorts rational thinking. [13]

Intuition or insight is not the same as instinct, and it is important to distinguish between them. Instinct is an innate, fixed pattern of behaving or emotionally reacting to some evolutionary significant stimulus. Humans fear snakes, prefer the familiar, and feel in-group loyalty and out-group rivalry. Several important hardwired instincts affect human decision making, and are usually thought to be irrational and damaging.

Insight or intuition provides a person with a self-convincing solution to a problem. The solution often comes suddenly and unexpectedly after a period of uncertainty and worry. Insight seems to require an incubation period that enables non-conscious processes to operate freely without rational analysis. Scientific insights may occur at a "eureka" moment, a flash and then "I have found it." [13]

Insight can be defined as "an understanding of cause and effect based on identification of relationships and behaviors within a model, context, or scenario." [14] Insight can occur after a person has acquired extensive experience with a particular kind of recurring situation. Unfortunately, expertise does not transfer to new and unfamiliar situations, so a strong insight can be very misleading.

6.2 Problems with using insight

There are several problems with depending on situational insight or intuition. First, intuition has no conscious basis and so it cannot easily be explained. After the fact justifications can seem weak, ad hoc, concocted. Second, intuition is specific to a particular field and is often far wrong if applied outside the area where it was acquired. Intuitions based on different experiences often clash. Third, since a decision maker's intuitions seem obviously right and are strongly emotionally confirmed, it is difficult to use System 2 to check them. Fourth, the real world is changing rapidly and intuition changes slowly as new experience is gained. A rapid real world change can invalidate learned expectations based on past history.

Humans tend to be overconfident, to underestimate uncertainty, to be excessively risk adverse, to ignore sunk costs due to loss aversion, to select alternatives using only the most salient differences, to select data to confirm past decisions, and to be influenced by irrelevant, perhaps unconscious motives.

Considering the prevalence of flawed heuristics and hidden personal and political agendas, intuitive judgments should be treated as important but highly suspect recommendations that need to be evaluated. It has been "suggested that the troublesome nature of automated (tacit) intuitive judgment may be addressed by raising the decision process to an explicit level through techniques such as devil's advocacy or balancing intuitive judgment with formal analytical tools (such as multi-attribute decision analysis and root cause analysis)." [13] It is important to recognize the strength and prevalence of intuitive decision methods, but it is necessary to challenge them with critical rational analysis.

7. Intuition can lead to bad decisions

Depending on "engineering judgment" can lead to disaster, as shown by the overconfidence that led to the unreliable space shuttle design.

7.1 Space shuttle design

The problems with shuttle originated with decisions made during Apollo. Risk analysis predicted that Apollo would suffer many fatalities before we reached the moon. This fear and the tragic Apollo 1 fire focused everyone on eliminating risk as much as possible. Anyone could raise an issue. But then, management discontinued risk analysis to avoid damaging public support for Apollo. The spectacular success of Apollo created over confidence and led to accepting too much risk in the space shuttle design.

Apollo risk was high. The "calculation was made by its architecting team, assuming all elements from propulsion to rendezvous and life support were done as well or better than ever before, that 30 astronauts would be lost before 3 were returned safely to the Earth. Even to do that well, launch vehicle failure rates would have to be half those ever achieved and with untried propulsion systems." [15]

The awareness of risk let to intense focus on reducing risk. "The only possible explanation for the astonishing success – no losses in space and on time – was that every participant at every level in every area far exceeded the norm of human capabilities. " [15]

However, this risk awareness was not considered appropriate for the public. The NASA Administrator felt that if the results were made public, "the numbers could do irreparable harm." The risk analysis effort was cancelled and NASA no longer used numerical risk assessment as a result. [16]

Unfortunately, the amazing success of Apollo led to extreme overconfidence. The head of Apollo reliability and safety decided, "Statistics don't count for anything," and that risk is reduced by "attention taken in design." This attitude was carried forward from Apollo to shuttle. A NASA safety analysis explained that shuttle "relies on engineering judgment using rigid and well-documented design, configuration, safety, reliability, and quality assurance controls." It was also thought that, with the attention given to safety and reliability, "standard failure rate data are pessimistic." [16]

Accepting too much risk in the design of the shuttle produced a system that was too dangerous. Unlike the hardened Apollo capsule heat shield, the shuttle crew compartment used fragile tiles, unlike the Apollo crew module, the shuttle crew compartment was next to rather than above the dangerous rockets, and unlike Apollo, the shuttle had no crew escape or launch abort systems. These design errors directly led to the Challenger and Columbia accidents. The current rocket and crew vehicle designs are similar to the safer design configuration of Apollo, with a hardened crew capsule, the crew capsule above the rocket and fuel, and a launch abort system.

The space shuttle was not designed for acceptable risk because the overall quantitative risk was not considered in its design. The ultimate cause of the shuttle tragedies was the choice by the Apollo-era NASA administrator to discontinue risk analysis to avoid damaging the Apollo program.

7.2 Equivalent System Mass (ESM)

The establishment of Equivalent System Mass (ESM) as the technology selection metric for space life support projects illustrates a similar judgment-based neglect of technical reality. ESM was established to advocate research in advanced life support research and to increase its funding. ESM is a measure of the total launch mass required to provide space life support, including the hardware mass, the logistics mass for parts and materials, and the allocated mass of the required power and cooling systems. Since recycling life support is used to reduce the need to launch large masses of water, oxygen, and other materials, making ESM the technology selection metric emphasizes the justification for recycling. In contrast, the standard NASA systems engineering approach uses LCC, which includes development, launch, and operations costs, and also emphasizes that many other systems considerations, such as performance, safety, risk, and reliability, should also be considered in technology selection. [17] [18] The great benefit of using recycling instead of material resupply was to reduce launch mass, but it is illogical to pursue only further mass reductions. Most of the original launch mass has already been saved. Recycling systems should now be engineered to trade back some of the mass savings to improve other system requirements, such as performance, safety, risk, and reliability. With the recent 20-fold reduction in launch costs, reducing launch mass is no longer a major consideration in life support design. This is another case where management judgment should be rationally checked using systems engineering methods, such as a checklist.

8. Politics is needed to resolve conflicts

Politics strongly affects project selection but it seems a necessary part of the budget allocation process.

8.1 Politics affects project selection

The intuitive approach recognizes that many factors in project selection are not explicitly known. "Much of the information used to evaluate candidate ideas and projects will necessarily judgmental in nature. Thus, individual differences in perspectives, viewpoints, and experiences may influence the appraisal and analysis. Organizational politics, departmental goals, and group loyalties may further influence the decision criteria and procedures." [6] Greater ambiguity and the need to use judgment and intuition encourage the use of power and politics. "(T)he more the ambiguity on goals or means to accomplish them, the more likely is the exercise of political power in decision making." [19]

Politics is expected. "R&D project selection processes are political in nature." "The signs of political confrontation and conflict emerge quite clearly from the analysis. The decision outcome is perceived as politically sensitive, and to have been made well in advance. The communication between the parties is perceived as bad. The decision outcome is strongly influenced by the top management, and people expect things to be dealt with neither fairly or honestly. It is likely to be a conflict process." [20]

8.2 Politics seems necessary

With limited resources, People with different goals and interests inevitably compete for priority and funding. Looked at practically, politics is the necessary process used to resolve such goal conflicts. Decisions must be made even when facts and logic are not sufficient.

Bolman and Deal define a political framework for analyzing organizations:

1. Organizations are <u>coalitions</u> of diverse interest groups and individuals,
2. They have <u>different goals</u> and beliefs,
3. The important <u>decisions allocate scarce resources,</u>
4. Scarce resources and different goals cause <u>conflict,</u>
5. Goals and decisions emerge from <u>bargaining and struggle</u> for resources. [8]

Conflicts over goals and funding are the cause of organizational politics and some process is needed to reconcile these conflicts. [21]

9. Fairness is important in project selection

In general, people expect that serious matters will be handled fairly. An organization's culture determines the "rules of the game" and people learn what to expect from "the system." Perceived injustice can reduce team members' commitment and effort.

Project selection should seem fair. "Procedural justice refers to the legitimacy of the methods used to make the decision." "(T)he following six factors influence perceptions of procedural justice: (1) consistency (the use of consistent procedures), (2) bias suppression (the absence of self-interest), (3) accuracy (the use of accurate information), (4) correctability (the presence of opportunities to correct the decision), (5) representativeness (all concerned parties adequately represented), and (6) ethicality (adherence to moral and ethical standards)." [22]

The use of reasonably rational and fair methods in project selection creates confidence and trust in the organization. [22]

10. Discussion

The logic behind the recommendation to implement a formal project selection process such as a checklist is as follows:

1. Organizations, projects, and project selection should be rational and are assumed to be rational.
    1.1. But they are not.
2. The reason is that human insight, intuition, and "gut feel," rather than reason, control decisions.
    2.1. Organizational and project decisions are made using unconscious individual and group psychology.
3. Nevertheless, we need to do rational project analysis and selection.
    3.1. The rational spirit is necessary for a scientific and technical organization.
    3.2. Professional ethics requires an open, honest, and fair process.
    3.3. Rational analysis can improve good projects and eliminate bad ones.
    3.4. A sanity check helps avoid egregious and embarrassing errors.

11. Conclusions

Many engineering methods have been developed to select projects, including quantitative metrics and qualitative success factors. One of the simplest is to use a checklist of criteria.

Project selection methods are little used, partly because they have not been proven effective. The main reason that formal project selection is not used is that managers strongly prefer to rely on their own judgment and "gut feel." Most management decisions use simplifying heuristics and reflect group biases. This often works well, but in unfamiliar and highly technical situations, natural human instincts, intuition, and even acquired technical expertise can fail and lead to grievous mistakes.

The approval of a project nearly always requires intuitive acceptance and group support, but often omits checking economic and technical rationality. It is more advisable to systematically doubt intuition and always rationally analyze projects before they are approved.

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