

Project Management Lecture

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Introduction

Research is not a generally well understood activity. The value of research is consistently downplayed by businesses and governments. Much activity has focused on identifying the value of R&D results to individual business and to national economies. This has not resulted in significant changes in the attitude towards R&D. The R&D manager tends to be isolated in a business, and operates differently from other managers. The management processes adopted differ from those in use in other parts of the organization. Project management is key to improving R&D processes and to creating a greater return on investment.

In this lecture we will review the context of Project Management and then consider what exactly is required in R&D project management. Following this we examine some of the detailed activities required for different phases of Project Management. The survey concludes with a review of some related questions about improving Project Management Performance.

1. Project Management context

1.1 Key Questions for R&D Management

1. Why cannot deliverables of research be more predictable in time and cost?

If costs and timescales may balloon, and if less result may be delivered than is needed, there are two different categories of risk, demanding simultaneous management. Typically both these are passed up to senior management to assess and deal with. The alternative is for the R&D manager to contain the cost and time risk within the R&D organization, and only pass up the outcome risk. It is up to R&D managers to improve their prediction skills, and to contain time and costs by becoming more efficient.

2. Why isn't the result of R&D more directly useful?

The usefulness depends on how well R&D understands the client. The gap between knowledge creation and its application requires many steps addressing many different constraints e.g. performance, reliability, manufacturability, cost. The initial R&D may not address all these issues. Hence the "result" of R&D is a slow moving transfer with

repeated iterations. The continuing involvement of researchers with production engineers, for example, requires a shared view of how to work.

3. Why can't we focus only on successful projects?

R&D is properly viewed as a risk-absorbing process, and not as a risk in itself. The researcher's task is to understand as much as possible about a problem, and then to deliver a successful outcome. Even though the scientific method is a systematic way of handling uncertainty, it cannot guarantee that there is a successful outcome. What is essential is the view that all projects are conditional and that every milestone is a possible termination point unless previously stated expectations are met. Hurdles or gates must be defined at the outset, or else the process is compromised.

1.2 Types of R&D

There are different labels for research:-

- Basic, applied
- Pure, applied
- Research, development

and research has many different goals:-

- Knowledge
- Demonstration, viability, proof of concept
- Production prototype

We should not expect that a single method of Project Management will fit all circumstances: but we cannot expand a common underlying framework.

Characteristic	Applied research	Pure research
Method	Trial and error i.e. continue trying until a trial succeeds.	Hypothesis and experiment i.e. there is learning from "failed" experiments
Focus	Single problem	Principle
Range	Incremental	Radical
Goal	Short-term, immediate	Long-term
Basis	Existing system	New system
Scope	Usually single or few parameters	Potentially holistic

Table 1: Comparison of two levels of R&D

Research produces technology. The results of technological change have been identified by Schumpeter as falling into five main categories:-

1. new processes i.e. new ways of producing existing products from existing inputs
2. new products i.e. new goods and services based on existing inputs
3. new sources or new types of raw material
4. new markets, either in the geographic sense or in new uses of existing products and services
5. new organizational methods i.e. new ways of controlling and organizing inputs.

Projects to address each of these outcomes will have different success factors: this is another source of variability in Project Management.

1.3 Performance management for R&D

The general benefits of performance management of R&D include:-

- the ability to make well-defined and appropriate decisions
- to limit and actively control the risk which R&D addresses
- to respond effectively to external questions about time and cost.

Fundamental to performance management is the concept of engagement, of the client, and of management, with the research team. R&D organizations may be characterized by the degree of involvement that they have with their clients and the extent to which research management in the organization is involved with the researchers. Both of these characteristics can be classified as engagement.

In a project two things happen in parallel: the requirement for the technology is clarified and the technology is developed.

1.3.1 Client engagement

Client engagement may vary from very limited e.g. the client may be known to use a particular technology and the R&D organization investigates and generally tries to develop that technology, to the very involved e.g. the research team includes people from the client organization. In general a high degree of engagement is considered good because it ensures that the R&D is directed at areas of real benefit to the client. It has the drawback that it may focus the organization on incremental approaches which can avoid fundamental problems.

1.3.2 Management engagement

Management engagement also varies widely. Some managers believe that R&D is fundamentally unmanageable, that innovations and breakthroughs cannot be planned, and that the researcher is essentially a self-managing entity. The extreme version of this view is less tenable where teams of researchers are required for a single project.

The other end of the spectrum has managers who look for project plans, ask for detailed expectations of outcomes, and take a very specific role in defining a project at the outset and following it through its course. This approach allows a manager to take action to terminate a project if it appears that a beneficial outcome is not going to be realized.

1.3.3 R&D management philosophies

If these two types of engagement are mapped onto a matrix diagram then the different philosophies of R&D management are clearly identified.

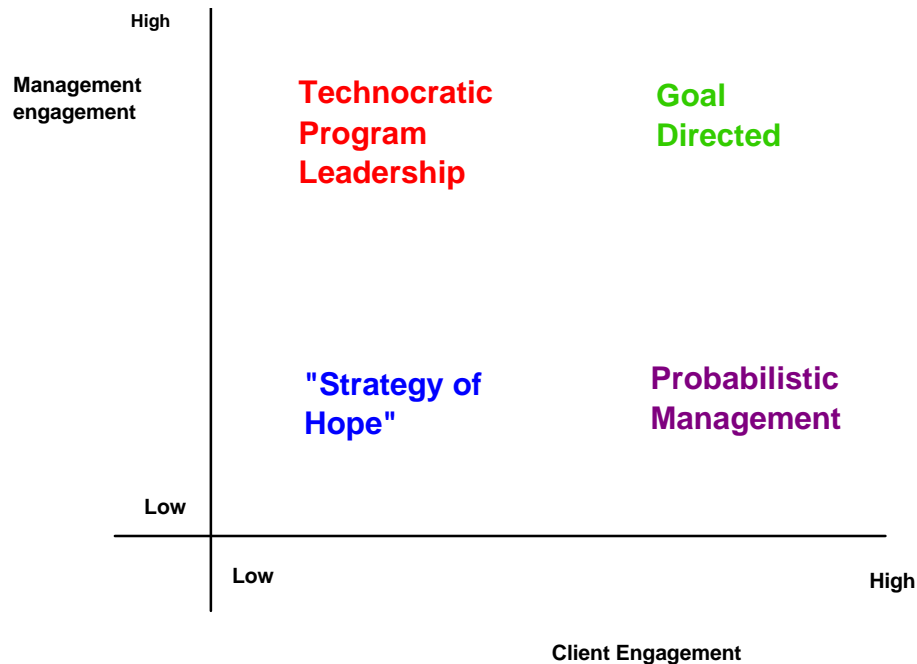


Figure 1: Degree of engagement matrix

1. Technocratic Program Leadership

places R&D managers in charge of selecting those technologies and those approaches within technologies, which are believed to offer significant technology improvement opportunities. This emphasizes technology push. It

will be characterized by significant breakthroughs and by low adoption rates: it will require considerable downstream effort in technology transfer.

The benefits of the approach are that knowledge of a technical field can be used to identify those areas where breakthroughs are likely to occur: this raises the yield rate. The drawbacks are the need to find a client and the time taken to adapt a technology to the client needs.

It is a viable option for an organization which has a marketing arm, for which technology is developed as a product, and technology transfer is a paid for service. Projects will be focused on addressing technical limitations: the requirement is largely seen as self-evident, or to be developed later.

2. Goal directed management

is characterized by low risk, small scale projects with well-identified returns. The rate of return may also be low, so control of costs is a critical factor for management. The technology developed is likely to be incremental, and the project will flow naturally into adoption. Researchers may be required as the technology is deployed to act as trouble-shooters and instructors. Hence the researcher needs a well rounded set of skills.

The benefits are the limited exposure offered by small scale projects and the likelihood of rapid, if limited, results. The drawbacks are that few breakthroughs will be achieved and a technology surveying function will be needed to avoid excessive investments in sunset technologies.

The approach works best where R&D is not a separate function for an organization but is integrated with line operations. Projects here require exact knowledge of requirements and will minimize the amount of technology investigation work, in favour of technology application.

3. "Strategy of Hope"¹

emphasizes the autonomy of the researcher. It depends on the recruitment of highly proficient individuals, who are strongly self-motivated. The management role is to ensure that these individuals are equipped with the facilities that they require. When a result is produced there will be a need to find a user for the technology, and for the researcher to explain their vision of how the technology may be employed. There are considerable uncertainties of when a result will be produced, what it will cost, and whether it can be successfully transferred out of the laboratory.

¹ This phrase comes from "Third Generation R&D", P.A. Roussel et al. HBS Press, 1991. The authors refer to a Harvard Business Review article by G. Hamel and C.K. Prahalad which described the Silicon Valley approach to innovation as "put a few bright people in a dark room, pour in money, and hope."

The benefits include limited management involvement and potential revolutionary gains. The drawbacks are the extreme uncertainty of outcomes, the difficulties of recruitment, and the problems of knowing when to call a halt. The method is good for the university environment or where fundamental research is key and hence transfer is not an immediate concern. Projects are usually very large, long-term and have a requirement which is expressed only in knowledge terms, not as a requirement.

4. Probabilistic management

depends on a portfolio of projects only a proportion of which are expected to be successful. Management role is to ensure that the projects selected into the portfolio have goals which are meaningful to the client, and that the resources employed for any single project do not unbalance the portfolio. Usefulness is generally assured, but costs and timing remain a major uncertainties and which projects will be successful is unknown until completion.

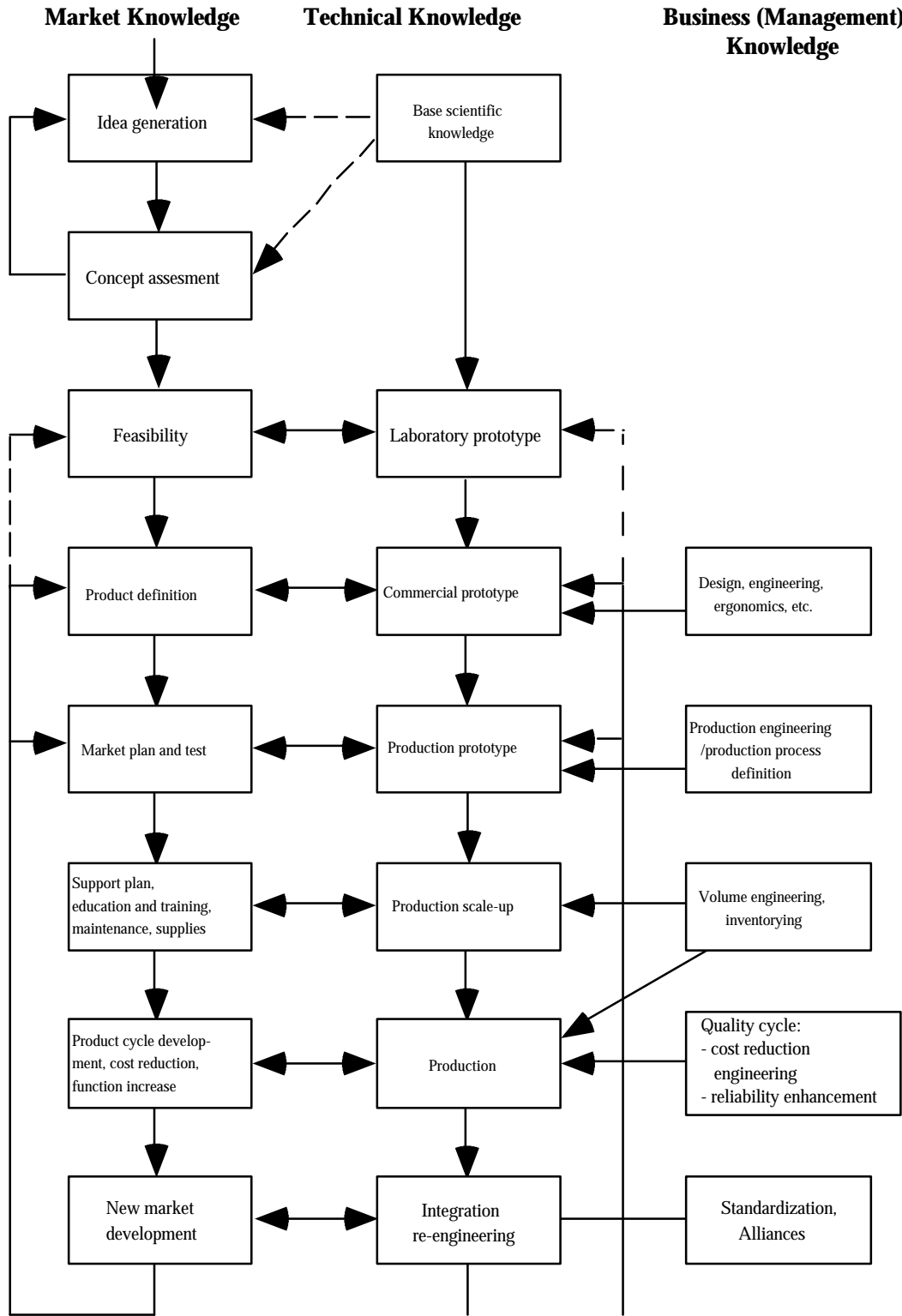
The benefit is the support that management can give to the client. The drawback is the problem of maintaining portfolio balance, particularly when projects over-run. This approach can only work for large organizations, which have sufficiently sizable portfolios to allow meaningful balance to be created. These projects have a balance of requirements and technology. They are closest to the entrepreneurial business development activity. Hence they may be seen as a valuable training ground for entrepreneurs.

	Technocratic leadership	Goal driven	Strategy of Hope	Probabilistic Management
Technology outcome emphasis	High	Low	High	Medium
Meeting requirements emphasis	Low	High	Low	Medium
Key success criterion	Platform for development i.e. multiple applications	Immediate application and benefit	Publication and prestige potential	Growth opportunity
Duration	Medium	Short	Long	Medium
Frequency of change of requirements	Low	High	Low	Medium

Table 2: Project characteristics comparison

1.4 Types of project

Figure 2



Projects usually occur in a sequence: the starting point is knowledge, the end point is a new product, a new process, etc. The project does not occur in isolation, and the scope of management is shown in Figure 2. A single project may encompass several of the boxes.

1.5 Success factors for projects and for project management

Experience with projects has led to some common observations about what factors lead to success. These have some obvious implications, and are summarized in the table below.

Success Factor	Implications
Use fewer and better people	smaller projects (fewer people, less time)
Fit the tasks to the skills and motivations of the people available	develop specific expertise, or use partners, or outsource
Provide opportunities for personal growth	training related to current and future expectations
Create a harmonious team	team development
Eliminate those who cause dissension	management expertise
Rigorous methods	discipline within project, not guesswork
Create and use productivity tools	the direct path is not necessarily the quickest
Don't make the schedule unnecessarily short	ideas take time to reach the ideal form
Keep the targets fixed	maintain focus by doing requirements work thoroughly
Create a positive work environment	rewards for goals reached

Table 3: managing for success

2. Project Management Overview

2.1 General

Project management is a central feature of technology management: it is delivery of a defined target on a defined date, at a defined cost. All the definitions need to be complete to allow for adequate management.

The exact nature of Project Management changes as we move from exploratory research to product development, but the core of discipline remains constant. At heart this work must be systematically planned and managed. Change is endemic, but it is directed change and not random change.

In multidisciplinary research, the team is assembled or committed at the outset and the project manager is the constant who stays with the task through to completion. The R&D manager is then something of a generalist. This implies that although general knowledge of technology exists, the detailed knowledge is not present, or cannot be assumed to be present: the generalist manager has a first responsibility for ensuring that the technical development of the R&D project is conveyed in meaningful terms to the organization as a whole.

2.1.1 Process with inputs and outputs

The R&D process has an idea or group of ideas as input and technology as output. Management options are to address the resources applied to the R&D process

Resources	Management options
People	Change people, add, subtract
Facilities	Enhance, add, modify, replace facilities
Training	Train with courses and experience
Process	Monitor and change process
Consumables	Control consumables
Clients	Communicate with client

Table 4: what managers can do

These are the things a manager can do: they are not the same as what the researchers do. The researcher is not necessarily a good R&D manager.

2.1.2 Management Intervention Cycle

The manager intervenes systematically in a project: these interventions are either on a regular schedule, known in advance, or when certain events happen. The details of this are discussed later. The principle of the intervention is as follows:-

1. The manager defines expectations and for each expectation will define the measurement associated with that expectation. The expectations can include specific goals to be attained, or resources consumed.
2. The project team will make the measurements and report them to the manager.
3. The manager will relate the measures to the expectations, and where there is a significant deviation will undertake a diagnosis in conjunction with the team.
4. The manager and the team will identify changes, within the scope of the management options, which will lead to improvement. The manager will authorize the changes and the team will implement them.
5. The project continues and the intervention cycle reverts to step 1.

2.2 Phases and elements

Project management starts with a definition of what is to be delivered and to whom, develops a plan for producing the result within time and cost bounds, and then resources and monitors the resultant project, adapting the plan as required during execution. The agreement on the form of the deliverable, and the tests it will pass are the crucial elements for ensuring the results of a project are accepted by the client. It may also be construed as the initial step in quality.

All the activities in project management are subject to constraints provided by the program management e.g. time, cost, resources available. By improving the efficiency of executing projects these constraints are relieved.

2.2.1 Project management Phases

1. Initiation
2. Scope, including Work Breakdown Structure
3. Work Package planning, estimating, identification and selection of best approaches
4. Scheduling, resource assignment
5. Measurement planning
6. Project execution, including monitoring and control
7. Review

2.3 Tools for R&D project management

- Research Estimator for resource management and progress establishment
- Outcome assessment
- Technology competence assessment

These tools will be reviewed during the detailed survey of project phases. N.B. most project planning tools are designed to deal with complexity and large scale, not with inherent uncertainty. Charts give an air of apparent precision which is misleading.

3. Project Initiation

3.1 Uncertainty: "Project Progress is an Uncertainty Reduction Process."

A clear identification of uncertainty is needed at the outset so that a plan to reduce uncertainty can be formed. The project manager needs to be able to objectively assess degree of uncertainty reduction and progress to goals. We should have both reduction in market uncertainty and in technological uncertainty. Project management should ensure that both progress together (as per Figure 2)

Early estimates of outcomes will have large uncertainties associated with them. However uncertainties at early stages are of less significance because relatively few resources are allocated. Peer review is often used. However if the view is taken that the researcher is a scarce resource, then the opportunity cost may be considerable. This requires the reduction of uncertainty at the earliest possible stage. If measures cannot be completely accurate, at least they should be consistent. If a series of projects are reviewed by different managers then the same ranking should ideally appear in all cases.

3.2 Project planning

Stage	Decision	Benefit
Commencement	<ul style="list-style-type: none"> • Is the undertaking financially worthwhile? 	<ul style="list-style-type: none"> • Avoidance of projects which have no or negative pay-off
Project planning	<ul style="list-style-type: none"> • Will the project achieve its goals? • What resources need to be assigned? • What facilities need to be assigned? • When will the results be available for subsequent use? 	<ul style="list-style-type: none"> • Avoidance of badly planned projects. • Optimal use of resources. • Optimal use of facilities. • Ability to plan accurately.
Project execution	<ul style="list-style-type: none"> • Is the project on track or has an unforeseen problem emerged? • Will the result be as expected? • What future requirements may be pre-planned? 	<ul style="list-style-type: none"> • Earlier and more accurate decisions re project termination or re-resourcing. • Maintenance of business perspective. • Ability to plan accurately and minimize lead times.
Project completion	<ul style="list-style-type: none"> • What improvements could have been made? 	<ul style="list-style-type: none"> • Project management improvement and research execution improvement.

Table 5: project manager decisions

During a project a number of decisions have to be made. The above table shows some of these and suggests the different emphases that are appropriate to different stages of projects.

The project manager executes a series of steps in project planning:-

- What is the basis of the project i.e. requirements, information re status quo. What specifically does the project have to do?
- What is the uncertainty and confidence level for the information?
- What information is needed to reduce uncertainty and increase the confidence level?

Example:

Basis: reduction of agricultural product loss due to weed infiltration.

Information: data on average loss levels, effectiveness of existing treatments.

Goal: find a more effective treatment, with lower environmental impacts.

Results: delivered to farmers, eventually.

Uncertainties: long term effectiveness of existing treatments, cumulative environmental impacts.

Information needed: what are the alternatives? what are the relevant performance measures?

This view provides a basis for starting a project and offers a reference point to return to if the outcomes start to be other than expected. This stage does not identify the technology that is expected, which in the example above, could be a more selective and effective weed treatment, or a crop variety which is more resistant to weed competition.

4. Project Scope

4.1 Objectives

Objectives may be classified as mandatory, as desirable, and as chosen.

Mandatory

These objectives will usually have some numbers associated with them and failure to reach the numbers means that the project is unsuccessful. e.g.

- Development cost
- Operation(logistics) cost
- Capital cost /Maintenance cost
- Compatibility with existing
- Operator skill level
- Ease of use
- Complementarity to existing
- Fixed laboratory use
- Mobile laboratory use
- Field use

Desirable

These objectives are nice to have, are often subjective, and may be simply defined as better than existing standards. Failure to meet them does not make the project unsuccessful e.g.

- Reliability
- Accuracy
- Robustness or ruggedness
- Fail safe or fail soft
- Sensitivity
- Discrimination
- Response time
- Resource consumption
- Cycle time
- Weight
- Size
- Replicability
- Range of operation
- Yield
- Operability
- Purity

There is not a hard line between these two groups: it could be that a purity level would be mandatory for a drug.

Chosen

These objectives are chosen as options for the project.

- Technology relative to existing: Existing/Improved/New
- Technology use: Existing/Improved/New
- Design: Existing/Improved/New

Absolute technology level: Basic/Pacing/Key

A basic technology is one which is in common use, a pacing technology is one which differentiates leaders in a field from others, and a key technology is one which is being introduced for its first applications.

At this stage the project manager will define all project objectives, and then identify what work is needed to reduce the uncertainty associated with each objective. Decisions will be made about whether all the objectives are equally achievable, whether the work required is uniform, and what are the trade-offs. This requires some technology input so the project manager will have to find appropriately qualified resources. A panel approach may be used to obtain a spectrum of opinions.

4.2 Deliverables

Characteristic	Data
Form of deliverable	Report only /Sample or data /Design /Software or Process /Laboratory prototype /Commercial prototype /Production prototype
Documentation	User and operations guide/Installation guide/Training/Maintenance/Diagnosis and repair/ Design specification/ Detailed construction plans/ Procedure/ Software/Test process and data /Assay results
Report level	Operational /State of Art review /Technical descriptive /Test data and performance / Technical theory
Phase reports	Phases requiring separate reports

Table 6: defining the deliverables

A crucial aspect for estimating the resources requirements is the deliverables and the form that they will take. The above table provides a systematic view of this. The deliverables may be at the end of the project or may be also at phases in the project.

4.3 Preliminary view of resource requirements

The defined requirements and deliverables provide a basis for estimating the total cost of the project, even before the work is defined in packages. In addition there is some data which can help define the work associated with each phase of the project.

Phase	Percent of total estimate
Planning and requirements	6%
Design	15%
Development	63%
Documentation and delivery	16%

To this should be added that for any project an additional 10% should be added to the estimate for the work done by management.

5. Work Package Planning

5.1 Planning Process

This is based on the scientific approach i.e.

- Hypothesis/experiment
- Phase goals
- Methodology choices
- Identification of resource types

5.2 Work Package development

This may be based on each information requirement treated separately or they may be clustered together. Each case needs an individual treatment. Key factors in the choices are uniformity of skill requirement and approximate equality of size.

Example

Design a better pesticide spray

Information collection activities:-

1. relationship between droplet size and range
2. mixing mechanisms
3. measurement process for droplet tests
4. modeling process for design performance predictions

Design activities:-

5. meeting performance requirements
6. meeting operational requirements
7. meeting cost and production requirements

Prototype activities:-

8. prototype production
9. testing
10. documentation

In all of these activities there will be iterations: there should be a limited number of iterations arising from one activity needing more from another.

5.3 Estimation based on Process

When the approach to a particular problem has been identified, then a further basis for estimation exists i.e. the process whereby the results required are created. This can be combined with the requirements data and the deliverables data to provide a more refined estimate. The following table shows the information required to create this refined estimate.

Characteristic	Data
Testing procedures	# of tests, and type of tests i.e. Standard(Equivalence) /Accuracy /Performance/Quality
Number of technology competences	
Status reporting requirement	# of reports required =
Facility requirements	Computing /Workshop /General Laboratory /Special purpose
Instrumentation	Existing /Enhanced /New
Procedure/methodology	Existing /Enhanced /New
Science activity	Known /Measurement of performance/Limits of performance / New research

Table 7: process characteristics for estimation purposes

5.3 Research estimator vs. Work Package view

Research estimator	Work Package units	Different impacts
Result focus	Activity focus	Minimize activity intervention to allow full creativity by researchers
Planning emphasis	Execution emphasis	Information available earlier in project
Flexible – goal oriented	Rigid – process oriented	Remains valid despite changes in approach
Ease of multidisciplinary approach – dynamic team	Static team	Not tied to a particular discipline
Learning approach	Limited learning	Formal framework for improvement
Supports innovation	Emphasizes existing approaches	Works even when a new approach is used for the first time.

Table 8: comparison of methods

6. Scheduling

6.1 Allocation of resources

6.1.1 Technology competence

A technology competence is a means of production: it is the capability of using a technology to deliver something of value. The value may be in the answer to a question, the design of a product, the definition of a process, or the change of an input. A technology competence depends on:-

- people and skills
- organization skills (processes, procedures)
- facilities
- requirement

to produce:-

- a result of value to meet requirements (reactive mode)
- a possibility of new value (proactive mode)

A technology competence may be measured by the combination of the quantity and quality of output. The performance of the technology competence may be measured as the average cost of a single execution. However, unlike a process which yields a final output, a technology competence may only yield an intermediate output i.e. something which is used further within the group producing it. Hence the performance calculation can become very subjective.

A research group is characterized by possessing a number of technology competences. The degree of competence possessed determines the quality of outputs that will be obtained and the range of problems that can be addressed. These factors can be appended to the technology competence descriptions as both examples and qualifiers for valid comparisons.

A technology competence is sustained by use and will evolve in time. As a greater variety of applications is experienced so the basis for determining how to proceed in a given case expands. As more applications occur, so improvements in method occur, making the technology competence application more efficient or more accurate.

A technology competence is generally a property of an organization and not of an individual: for example, as identified below, it includes facilities and procedures.

A technology competence may be formally described by:-

1. a name stating concisely what it is.
2. defined inputs and outputs
3. facilities employed in the course of using the technology competence
4. instrumentation enhancement
5. tools which allow the technology competence to be efficient in use. Such tools will be developed as the technology competence is employed more times and hence the effort invested in creating the tools can be recovered.
6. experience i.e. the occasions on which the technology competence has been employed and has met expectations.
7. training and education i.e. what has qualified those who deliver the technology competence to do so?
8. infrastructure which may be used to demonstrate the quality of the delivered result or to provide an independent assessment of the result, or to act as a support to the technology competence in providing additional information, test results, testing procedures or applicable standards.
9. management capability i.e. the tools which allow the accurate estimates of resources and time to be made.
10. some economic impact i.e. through economy of scale, economy of specialization.
11. technology surveying capability for internal or external use.

All this points to the care required to define a technology competence and to adequately characterize it. This should be performed by someone external to the organization to ensure adequate objectivity.

The evidence for technology competence strength is based on some key factors. Among the elements which define the technology competence are some which are closely related to strength. Strength is regarded as being able to adapt the technology competence to a variety of circumstances, to produce a rapid response, to have routinized basic elements to create efficiency and to have a well-defined managerial process. The key factors with respect to strength in the technology competence description are:-

- instrumentation enhancement
- efficiency tool production and use
- management process
- technology surveying

Instrumentation² is one of the areas where innovation is dominated by users. The diffusion path is via manufacturers who adopt the innovation and the user fora at which innovations are reviewed amongst peers.

6.1.2 Allocation

Each activity must be classified as requiring a defined set of technology competences, which will, in turn, imply a facility requirement.

² E. von Hippel, "Sources of Innovation", Oxford, 1988, Ch.2 "Users as Innovators"

Example

Pesticide spray

Activity	Technology competence
1. relationship between droplet size and range	Atmospheric physics
2. mixing mechanisms	Fluid mechanics
3. measurement process for droplet tests	Instrumentation, trace substance detection
4. modeling process for design performance predictions	System design, modeling tools
5. meeting performance requirements	Product engineering
6. meeting operational requirements	Product engineering
7. meeting cost and production requirements	Production engineering
8. prototype production	Product engineering
9. testing	Test and evaluation
10. documentation	Documentation

Ideally multi-skilled individuals are employed. Small packages of work can be outsourced if needed: the package definition facilitates this.

6.2 Scheduling

A PERT chart can be constructed to show the dependencies of the work packages and the timelines to completion. There are a number of practicalities which arise:-

- where multiple activities are undertaken by individuals, there may not be sufficient freedom to construct an ideal schedule.
- the constraint of having a facility and the people available at the same time further reduces the number of options
- the accuracy of the estimates used is low: the chart will be frequently updated.

7. Measurement Planning

7.1 Probability estimates

Any measurement has a degree of estimation in it. For example, the number of days consumed to date may be known, but the degree of completion is only an estimate. The existence of work packages helps to provide more scale points into the estimating process, but there is still room for error.

For each estimate a confidence level can be requested. This allows a second type of measure to be used for tracking purposes. We can use the percentage completion as one measure and the confidence of the estimate as a second measure. Progress may be made by increasing the confidence level of an estimate, even if the estimate itself does not change. If both measures decline then there is serious trouble.

We can try to make the estimation process more objective. A group process is useful: the group membership includes the project manager, the project leader, or the senior team members, and an external peer researcher. The steps followed are:-

1. Discussion and agreement of what are the governing factors.
2. Discussion of the evidence related to each governing factor
3. Independent estimates are made and then shared.
4. If they are close, the process stops, otherwise the process iterates with focus on the points which are seen as most variable by the members of the group.

Example

A software project

Governing factors: the phase reached, number of modules completed for that phase.

Evidence: status for each module

Estimates: probably based on the expectation that modules are about uniform in size, therefore the number completed in that phase shows how complete the phase is.

7.2 Comparison of actuals to estimates

Measurement depends on the degree to which expectations are realized. This may be the objectives that have been attained, or the work packages which have been completed. Therefore the existence of detailed expectations before hand is absolutely critical.

Two measures are significant; the first is the achievement of something, either a work package or an objective. The second is the ability to show ongoing progress towards a goal. In this scheme mandatory requirements determine success: desirable objectives are really quality measurements i.e. how well the work was done.

8. Execution

8.1 Exceptions

Exceptions are either temporary, in which case the project team handle them as part of their iterative process of reaching goals, or permanent, in which case the project manager must act.

Cases

1. Project fails to meet a mandatory goal

Response: Halt entire project for review until a new possible path to reach the requirements is found. The restart the project, including reassessing its economic sense. If no path is found the project is stopped completely.

It may be appropriate to determine that the goal as defined really was mandatory: there may be trade-off to be obtained. This reason for continuing should be rare if the project is planned properly.

2. Key resource is lost e.g. leaves, or is required elsewhere.

Response: Reassign responsibilities where possible. Restaff remaining work (outsource is an option). Reschedule the project. Restart.

3. Client changes requirement

Response: halt project. Replan as new project. Start new project.

4. Client no longer wants deliverable

Response: terminate project.

5. Facility inadequate

Response: halt project. Can the project bear the investment in a new facility, or an upgrade? If yes then reschedule the project and restart.

If no then put the project on hold till the facility is changed.

8.2 Assessment

Measurements should be made at the end of each work package, and every month. Clearly to avoid administrative burden the assessment process must be relatively light.

8.3 Modification

Where problems arise e.g. resource over-run, then a rescheduling process should be used, provided there is reasonable certainty that the goals can be achieved within the new estimates. It is key to understand why the original estimates were wrong.

8.4 Results

Results are either prompt or deferred: the key is to ensure that all results are known and captured.

Prompt

1. Project results, which contribute to a program goal
2. Project results which eliminate an option
3. Trained people (technology competences)
4. Facilities
5. Instrumentation
6. Processes and procedures
7. Knowledge and intellectual property
8. Links to peers, survey of field, technology forecast.

Deferred

1. Exploitation of results (systems, products, processes, services, inputs) which translate into dollars, higher performance levels, new abilities
2. Training of users
3. Organization image
4. Program shaping (what you do and how you do it)
5. Improvement
6. Redefinition of business, or of opportunity

8.5 Project Termination

Conditions for terminating projects

- a) market disappears
- b) output is no longer strategic to the organization
- c) technology can be purchased or obtained elsewhere
- d) cost over-runs or projected over-runs make the project unviable.
- e) time over-runs or projected over-runs make the project unviable.
- f) estimates are increasing and uncertainty is not reducing
- g) targets are changing continually, and particularly downwards without trade-offs.
- h) critical targets are demonstrated as not achievable by this technology.

9. Review

9.1 Diagnostics

Project management performance can be reviewed on two grounds:-

1. process used
2. individual performance

Estimates tend to be not very good, but can, with attention be made to improve. Some data on the ratio of actual to estimates collected by Mansfield found the following:-

Cost estimates:	1.78 (std dev 0.74)
	88% over-ran costs
Time estimates:	1.61 (1.15)
	68% over-ran time

Labour cost is a high component of total R&D cost. If time ratios exceed cost ratios, this implies that there are delays, rather than higher work content. If cost exceeds time, probably more labour was added to the project team. If the ratios drop over time the organization may be learning.

We should expect that less innovative projects have less uncertainty than highly innovative projects i.e. basic research. If not then the organization has little learning capability.

9.2 Efficiency

Efficiency in research is a neglected area: if a management focus on efficiency were adopted, the compatibility of management processes between R&D and other departments would be increased. Efficiency can be measured in three different ways, which yield compatible results.

The results obtained from a recent study suggest that an average of a 2 times performance improvement could be obtained by addressing research efficiency. Benchmarking, based on technology competence, is a crucial technique for measurement and for identifying performance improvements.

9.3 General areas for performance improvement

Where can efficiency gains be made? The following general areas have been identified as leading to efficiency improvement. Reductions may be achieved either through the elimination of unrequired activities, batching similar tasks, or through higher levels of mechanization. Managers have to judge what is required and benchmarking is a useful guide for this.

1. Reduction in numbers of tests required.
2. Reduction in number of retests
3. Increase in unequivocal outcomes
4. Reduction in set-up times
5. Reduction in data collection times
6. More comprehensive data collection
7. Reduction in data analysis times
8. Reduction in calibration and standardization times
9. Increase in sensitivity of measurements
10. Increase in specificity of measurements
11. Reduction of project planning times
12. Reduction in project results reporting times
13. More use of existing data
14. Ability to run more projects in parallel (with consequent reduced non-productive time)

10. Conclusions

Each R&D group has its unique attributes, and each area of research has its unique problems. However there is also a great deal of commonality and these common factors allow the process to be managed and allow the organization to learn.

Some conventional wisdom can be used to help project managers:-

- Projects get done faster if an organization takes on fewer at a time.
- Investments to relieve bottlenecks can be highly effective in time-to-market benefits.
- Stabilizing workloads enhances focus on creativity.
- Creating cross-functional work teams to reduce rework cycles can result in some individuals working on too many projects at once.
- Product development can be usefully thought of as a production process with projects moving through the knowledge equivalent of a job-shop.
- Concept development is a joint process between marketing and engineering.
- Projects to implement new technology, should ensure that the technology survives the implementation.