Pearson BTEC Higher Nationals in Electrical and Electronic Engineering (QCF)

Unit 4: Managing a Professional Engineering Project

Unit Workbook

Learning Outcomes:

Formulate, Plan, Conduct, and Present a Report on a Project that provides a Solution to an Identified Engineering Problem

1 INTRODUCTION TO PROJECTS

1.1 What is a Project?

A Project is a temporary endeavour undertaken to create a unique product, service or result. It is temporary in the sense that it has a defined beginning and end, and therefore a defined scope and finite resources. It is unique in the sense that it is not a routine operation, but a specific set of operations designed to accomplish a singular goal. In this unit, we are specifically concerned with engineering projects.

Project management, then, is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. The purpose of project management is to **Initiate** the project, **Plan** and **Execute** the activities necessary for the project to progress, to provide project **Monitoring and Control**, and finally to **Close** the project.

It has always been practiced informally, usually by the engineers, architects or master builders who conceived the project design but it began to emerge as a distinct profession in the 1950s when organisations started to systematically apply project-management tools and techniques to complex engineering projects.

1.2 The History of Project Management

As a discipline, project management developed from several fields of application including civil construction, engineering, and heavy defence activity. Two forefathers of project management are Henry Gantt, called the father of planning and control techniques, who is famous for his use of the Gantt chart as a project management tool, and Henri Fayol for his creation of the five management functions that form the foundation of the body of knowledge associated with project and program management. Both Gantt and Fayol were students of Frederick Winslow Taylor's theories of scientific management. His work is the forerunner to modern project management tools including work breakdown structure (WBS) and resource allocation.

The 1950s marked the beginning of the modern project management era where core engineering fields come together to work as one. Project management became recognized as a distinct discipline arising from the management discipline with engineering model. Prior to the 1950s, projects were managed on an ad-hoc basis, using mostly Gantt charts and informal techniques and tools. At that time, two mathematical project-scheduling models were developed. The Critical Path Method (CPM) was developed as a joint venture between the DuPont Corporation and Remington Rand Corporation for managing plant maintenance projects. The Program Evaluation and Review Technique (PERT), was developed by the U.S. Navy Special Projects Office in conjunction with the Lockheed Corporation and Booz Allen Hamilton as part of the Polaris missile submarine program.

PERT and CPM are very similar in their approach but still present some differences. CPM is used for projects that assume deterministic activity times where the times at which each activity will be carried out are known. PERT, on the other hand, allows for stochastic activity times where the times at which each activity will be carried out are uncertain or varied. Because of this core difference, CPM and PERT are used in different contexts. These mathematical techniques quickly spread into many private enterprises.

At the same time, as project-scheduling models were being developed, technology for project cost estimating, cost management and engineering economics were evolving.

Project management is, by definition, an interfacing and an integrating activity and its description requires first an understanding of the associated functions such as engineering, quality assurance, procurement and accounting.

1.3 Project Fundamentals

The main characteristic of any project is its novelty; every project is different, even a repeated one.

Every significant project, therefore, should begin with a definition and business case that defines the project and forecasts the investment required and the expected benefits. That business case (business plan) should be approved before any money and other resources are committed to the project. For a large project, though, preparation of the business plan itself can need considerable money and other resources.

The purpose of project management, then, is to plan, organize and control all activities so that the project is completed as successfully as possible despite any difficulties that may occur. The key here is to make the stakeholders happy by fulfilling the expected deliverables.

1.4 Project Objectives

A project comes about because of an identified need. For example, we would identify a need to construct a power station because we need to produce more electricity. Well fine! But what sort of power station do we need; a gas-fired station, a coal-fired station, a bio-mass power station, a nuclear power station, or something else. The ultimate choice will depend on many factors that encompass budgetary, environmental, political, and other considerations. The business plan would no doubt be a weighty tome that would take considerable resources to complete. Just consider how long it has taken the UK to decide on whether it will construct further nuclear power stations.

Once the decision has been made, however, and the project has been given the go ahead, there will be three primary objectives will be used to judge the success, or otherwise of the project. These are:

1. The project satisfies its specification and delivers the intended benefit.
2. The project is completed within the agreed timescales.
3. The project is completed within the agreed budget of resources, i.e. cost.

In an ideal world, all three objectives will be fulfilled, but in practice, there are usually compromises and complex trade-offs which are made between each of these objectives. For example, Eurotunnel was late in delivery and seriously overspent, but is perceived by users as a great success.

1.5 Project Organisation

The people and organisations involved in an engineering project are many and diverse and there are no simple boundaries or interfaces that exist between them. For the sake of simplicity here we will employ the following terminology;

Customer: The person, people, or organisation that own and finance of the project.

Contractor: The person or people who carry out the project work during the execution stage.

Project Manager: The individual who assumes responsibility for the complete project.

1.6 Project Life Cycle

1.6.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support. Reliable LCA performance is crucial to achieve a life-cycle economy. The International Organisation for Standardisation (ISO), a world-wide federation of national standards bodies, has standardised this framework within the series ISO 14040 on LCA.

1.6.2 The Phases of Life Cycle Assessment

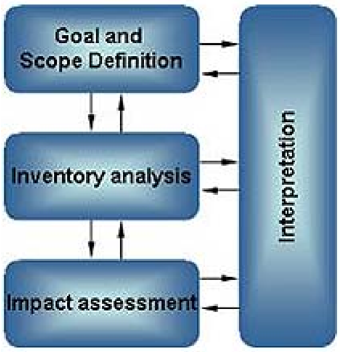

Figure 1 The Phases of Life Cycle Assessment

1. Goal and Scope Definition, the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined,
2. Inventory Analysis of extractions and emissions, the energy and raw materials used, and emissions to the atmosphere, water and land, are quantified for each process, then combined in the process flow chart and related to the functional basis;
3. Impact Assessment, the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance;
4. Interpretation, the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

A separate section devoted entirely to Life Cycle Assessment is provided at the end of the workbook.

2 PROJECT STAGES

For the overall success of the project each stage of the project, Project Initiation, Project Planning, Project Executing, Project Monitoring and Control, and Project Closeout must be accomplished successfully. These will each be considered in turn.

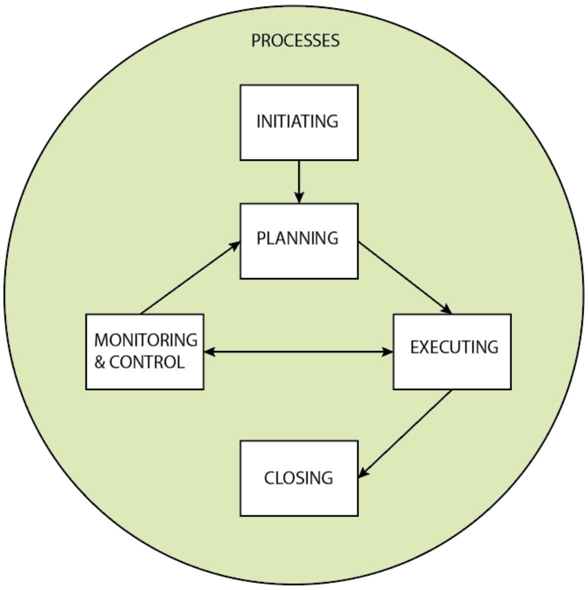

Figure 2 The Project Development Cycle

2.1 Project Initiation

The initiating processes determine the nature and scope of the project. If this stage is not performed well, it is unlikely that the project will be successful in meeting the business' needs. The key project controls needed here are an understanding of the business and engineering environment and making sure that all necessary controls are incorporated into the project. Any deficiencies should be reported and a recommendation should be made to fix them.

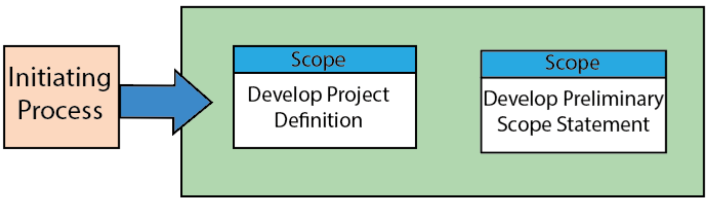

Figure 3 Initiating Processes

The initiating stage should include a plan that encompasses the following areas:

- analysing the business and engineering needs / requirements in measurable goals
- reviewing of the current operations

- financial analysis of the costs and benefits including a budget
- stakeholder analysis, including users, and support personnel for the project
- project definition including costs, tasks, deliverables, and schedules
- SWOT analysis strengths, weaknesses, opportunities, and threats to the business

2.2 Planning

After the initiation stage, the project is planned to an appropriate level of detail (see example of a flow-chart, Figure 4.). The main purpose is to plan time, cost and resources adequately to estimate the work needed and to effectively manage risk during project execution. As with Initiation, a failure to adequately plan greatly reduces the project's chances of successfully accomplishing its goals.

Project planning generally consists of;

- determining how to plan (e.g. by level of detail or Rolling Wave planning),
- developing the scope statement,
- selecting the planning team,
- identifying deliverables and creating the work breakdown structure,
- identifying the activities needed to complete those deliverables and networking the activities in their logical sequence,
- estimating the resource requirements for the activities,
- estimating time and cost for activities,
- developing the schedule,
- developing the budget,
- risk planning,
- developing quality assurance measures, and
- gaining formal approval to begin work.

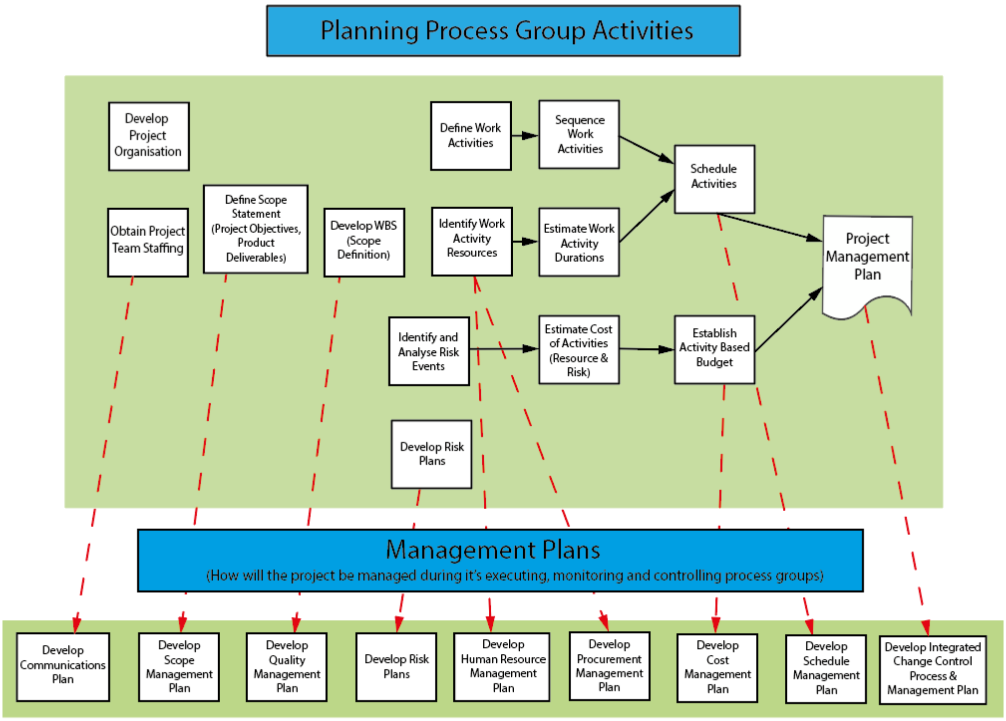

Figure 4 Flowchart for Planning Process Group Activities

Additional processes, such as planning for communications and for scope management, identifying roles and responsibilities, determining what to purchase for the project and holding a kick-off meeting are also generally advisable.

For new product development projects, conceptual design of the operation of the final product may be performed concurrent with the project planning activities, and may help to inform the planning team when identifying deliverables and planning activities.

2.3 Executing

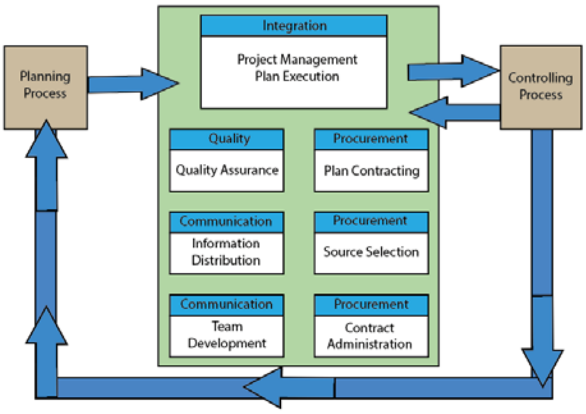

Figure 5 Executing Processes

While executing we must know what are the planned terms that need to be executed. The execution/implementation phase ensures that the project management plan's deliverables are executed accordingly. This phase involves proper allocation, co-ordination and management of human resources and any other resources such as material and budgets. The output of this phase is the project deliverables.

2.4 Monitoring and Control

Monitoring and controlling consists of those processes performed to observe project execution so that potential problems can be identified in a timely manner and corrective action can be taken, when necessary, to control the execution of the project. The key benefit is that project performance is observed and measured regularly to identify variances from the project management plan.

Monitoring and controlling includes:

- Measuring the ongoing project activities ('where we are'),
- Monitoring the project variables (cost, effort, scope, etc.) against the project management plan and the project performance baseline (*where we should be*),
- Identifying corrective actions to address issues and risks properly (*How can we get on track again*), and
- Influencing the factors that could circumvent integrated change control so only approved changes are implemented.

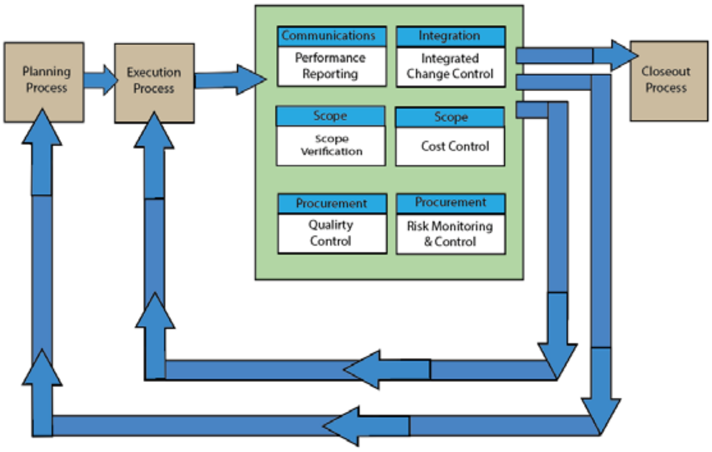

Figure 6 Monitoring and Control Process

In multi-phase projects, the monitoring and control process also provides feedback between project phases, to implement corrective or preventive actions and to bring the project into compliance with the project management plan.

Project maintenance is an ongoing process, and it includes:

- Continuing support of end-users,
- Correction of errors, and
- Updates to the product over time

In this stage, auditors should pay attention to how effectively and quickly user problems are resolved.

Figure 7 Monitoring and Control Cycle

Over the course of any engineering project, the work scope may change. Change is a normal and expected part of the engineering process. Changes can be the result of necessary design modifications, differing external conditions, material availability, contractor-requested changes, value engineering and impacts from third parties, to name a few. Beyond executing the change in the field, the change normally needs to be documented to show what was actually constructed. This is referred to as change management. Hence, the owner usually requires a final record to show all changes or, more specifically, any change that modifies the tangible portions of the finished work. The record is made on the contract documents, usually, but not necessarily limited to, the design drawings. The end-product of this effort is what the industry terms as-built drawings, or more simply, "as built." The requirement for providing them is a norm in engineering contracts. Engineering document management is a highly important task undertaken with the aid an online or desktop software system, or maintained through physical documentation. The increasing legality pertaining to the engineering industries maintenance of correct documentation has caused the increase in the need for document management systems.

When changes are introduced to the project, the viability of the project must be re-assessed. It is important not to lose sight of the initial goals and targets of the projects. When the changes accumulate, the forecasted result may not justify the original proposed investment in the project. Successful project management identifies these components, and tracks and monitors progress to stay within time and budget frames already outlined at the commencement of the project.

2.5 Closing

Closing includes the formal acceptance of the project and the ending thereof. Administrative activities include the archiving of the files and documenting lessons learned.

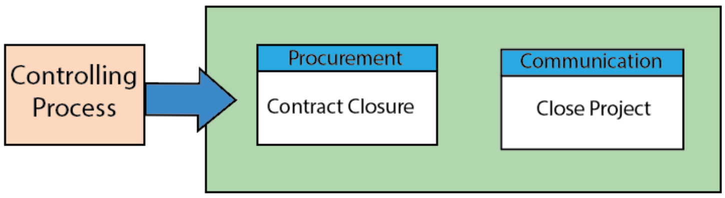

Figure 8 Closing Process Flowchart

This phase consists of:

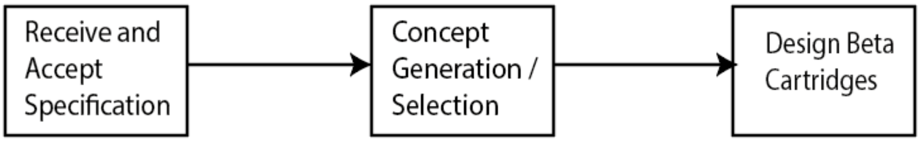

Figure 9 Sequential Task Dependency

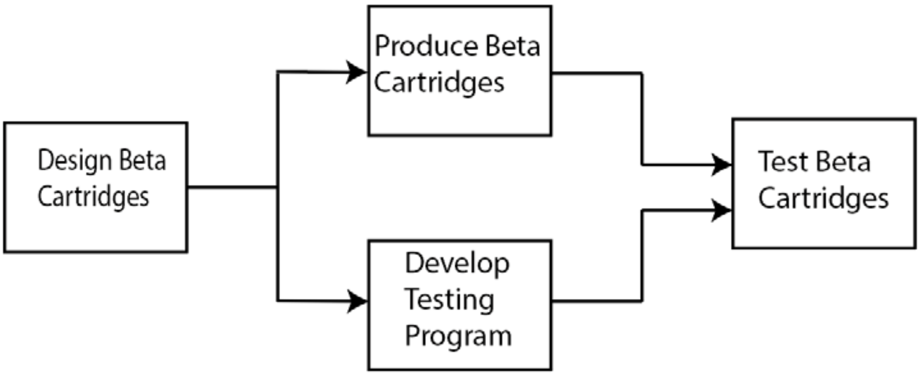

Figure 10 Parallel Task Dependency

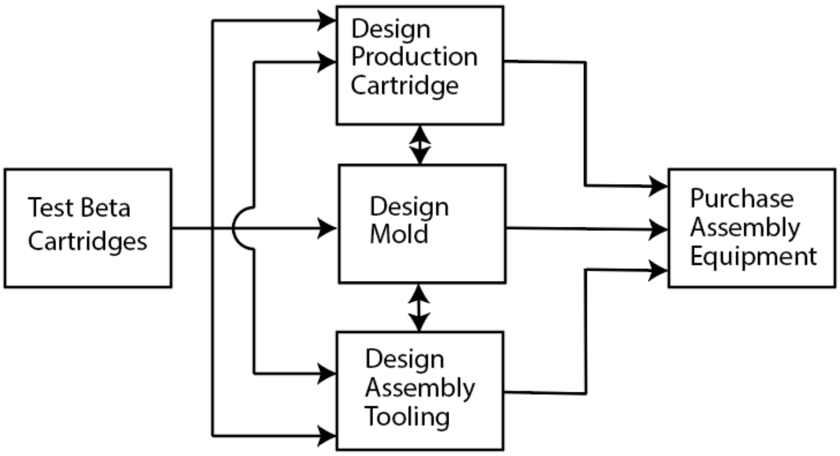

Figure 11 Coupled Task Dependency

Figure 9. shows three tasks, two of which are dependent on the output of another task. These tasks are **sequential** because the dependencies impose a sequential order in which the tasks must be completed. (Note that "completed", here does not necessarily mean that the later task cannot be started before the earlier one has been completed. Generally, the later task can begin with partial information but cannot finish until the earlier task has been completed. Figure 10. Shows four development tasks. The middle two tasks depend only on the task on the left, but not on each other. The task on the right depends on the

middle two tasks. We call the middle two tasks **parallel** because they are both dependent on the same task but are independent of each other. Figure 11. shows five development tasks, three of which are **coupled**.

Coupled tasks are mutually dependent; each task requires the result of the other tasks in order to be completed. Coupled tasks either must be executed simultaneously with continual exchanges of information or must be carried out in an iterative fashion. When coupled tasks are completed iteratively, the tasks are performed either sequentially or simultaneously with the understanding that the results are tentative and that each task will most likely be repeated one or more times until the team converges on a solution.

3.1.2 The Design Structure Matrix

A useful tool for representing and analysing task dependencies is the design structure matrix (DSM). This representation was originally developed by Steward (1981) for the analysis of design descriptions and has more recently been used to analyse development projects modelled at the task level. Figure 12 shows a DSM for the 14 major tasks of the Cheetah project (Kodak's actual plan included

more than 100 tasks.)

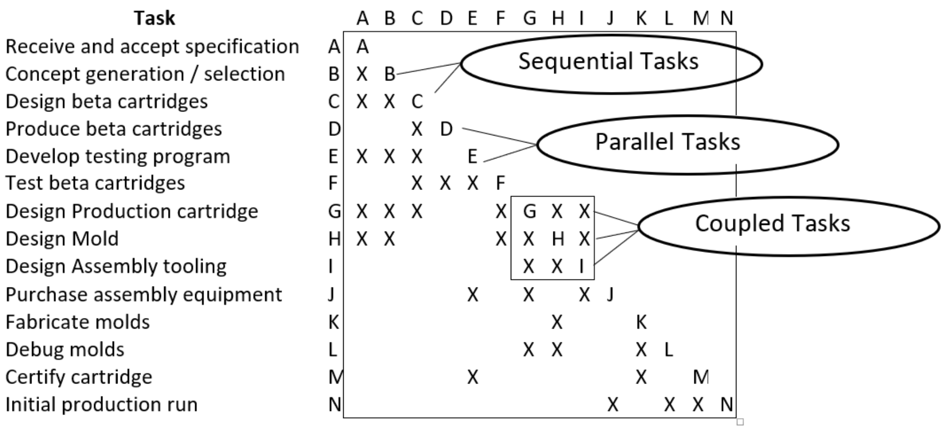

Figure 12 Simplified design structure matrix for Project X

In a DSM model, a project task is assigned to a row and a corresponding column. The rows and columns are named and ordered identically, although generally only the rows list the complete names of the tasks. Each task is defined by a row of the matrix. We represent a task's dependencies by placing marks in the columns to indicate the other tasks (columns) on which it depends. Reading across a row reveals the tasks whose output is required to perform the task corresponding to the row. Reading down a column reveals which tasks receive information from the task corresponding to the column. The diagonal cells are usually filled in with dots or the task labels, simply to separate the upper and lower triangles of the matrix and to facilitate tracing dependencies.

The DSM is most useful when the tasks are listed in the order in which they are to be executed. In most cases, this order will correspond to the order imposed by sequential dependencies. Note that if only sequentially dependent tasks were contained in the DSM, then the tasks could be sequenced such that the matrix would be the lower triangular; that is, no marks would appear above the diagonal. A mark appearing above the diagonal has special significance; it indicates that an earlier task is dependent on a later task. An above-diagonal mark could mean that two sequentially dependent tasks are ordered backward, in which case the order of the tasks can be changed to eliminate the above diagonal mark. However, when there is no ordering of the tasks that will eliminate an above-diagonal mark, the mark reveals that two or more tasks are coupled.

Changing the order of tasks is called sequencing or partitioning the DSM. Simple algorithms are available for partitioning DSMs such that the tasks are ordered as much as possible according to the sequential dependencies of the tasks. Inspection of a partitioned DSM reveals which tasks are sequential, which are parallel, and which are coupled and will require simultaneous solution or iteration. In a partitioned DSM, a task is part of a sequential group if its row contains a mark just below the diagonal. Two or more tasks are parallel if there are no marks linking them. As noted, coupled tasks are identified by above-diagonal marks. Figure 12. shows how the DSM reveals all three types of relationships.

More sophisticated use of the DSM method has been a subject of research at MIT since in the l 990s. Much of this work has applied the method to larger projects and to the development of complex systems such as automobiles and airplanes. Analytical methods have been developed to help understand the effects of complex task coupling; to predict the distribution of possible project completion times and costs; and to help plan organization designs based on product architectures.

DSM practitioners have found that creative uses of the DSM's graphical display of project task relationships can be highly insightful for project managers in both the planning and execution phases.

3.1.3 Gantt Charts

The traditional tool for representing the timing of tasks is the Gantt chart. Figure 13. shows a Gantt chart for Project X. The chart contains a horizontal time line created by drawing a horizontal bar representing the start and end of each task. The filled-in portion of each bar represents the fraction of the task that is complete. The vertical line in Figure 13. shows the current date, so we can observe directly that task D is behind schedule, while task E is ahead of schedule.

A Gantt chart does not explicitly display the dependencies among tasks. Task dependencies constrain, but do not fully determine, the timing of the tasks. The dependencies dictate which tasks must be completed before others can begin (or finish, depending on the nature of the dependency) and which tasks can be completed in parallel. When two tasks overlap in time on a Gantt chart, they may be parallel, sequential, or iteratively coupled. Parallel tasks can be overlapped in time for convenience in project scheduling because they do not depend on one another. Sequential tasks might be overlapped in time, depending on the exact nature of the information dependency. Coupled tasks must be overlapped in time because they need to be addressed simultaneously or in an iterative fashion.

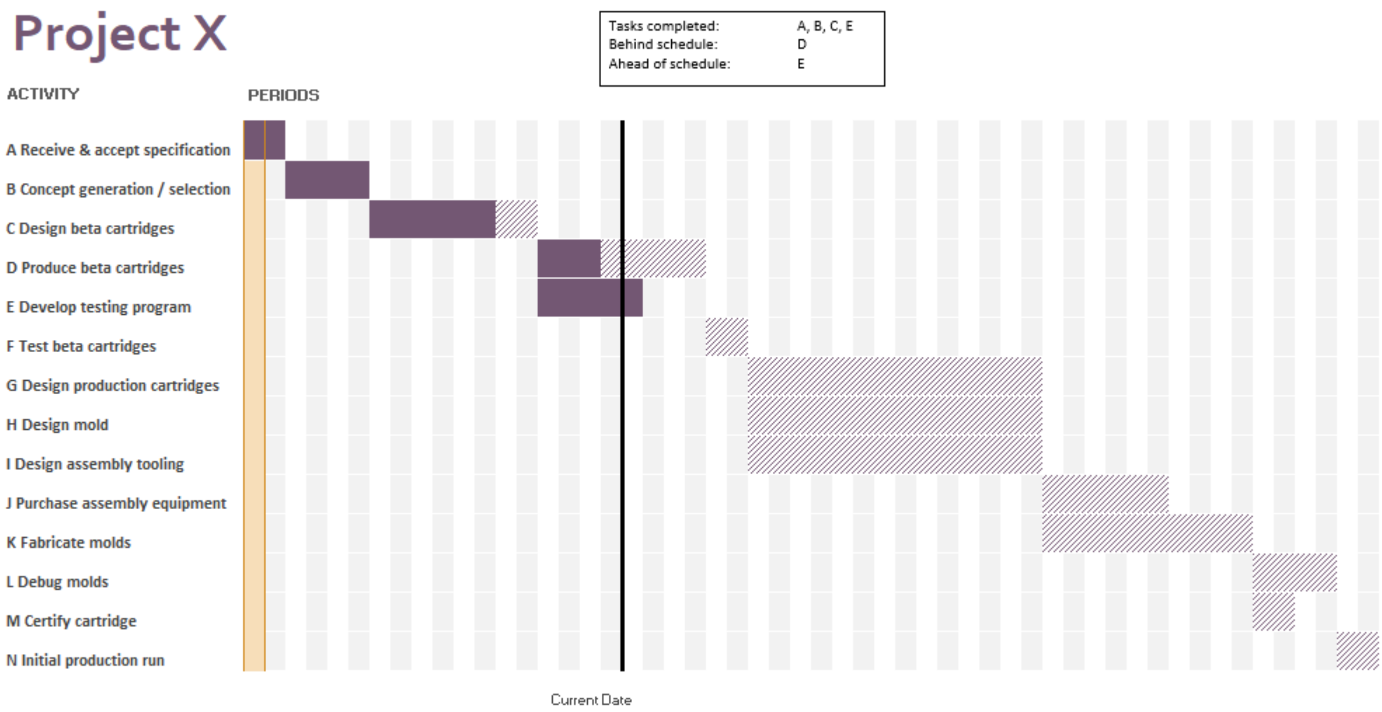

Figure 13 Gantt Chart for Project X

3.1.4 PERT Charts

PERT (Program Evaluation and Review Technique) charts explicitly represent both dependencies and timing, in effect combining some of the information contained in the DSM and Gantt chart. While there are many forms of PERT charts, preference lies with the "activities on nodes" form of the chart, which corresponds to the process diagrams that most people are familiar with. The PERT chart for Project X is shown in Figure 14. The blocks in the PERT chart are labelled with both the task and its expected duration. Note that the PERT representation does not allow for loops or feedback and so cannot explicitly show iterative coupling. As a result, the coupled tasks G, H, and I are grouped together into one task. The graphical convention of PERT charts is that all links between tasks must proceed from left to right, indicating the temporal sequence in which tasks can be completed. When the blocks are sized to represent the duration of tasks, as in a Gantt chart, then a PERT diagram can also be used to represent a project schedule.

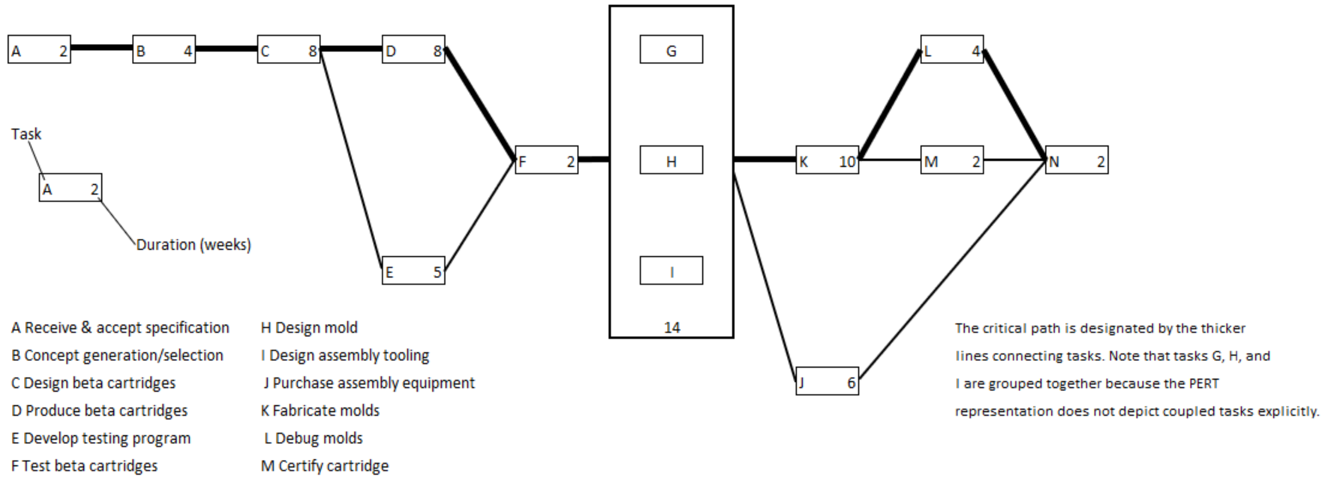

Figure 14 PERT Chart for Project X

3.1.5 The Critical Path

The dependencies among the tasks in a PERT chart, some of which may be arranged sequentially and some of which may be arranged in parallel, lead to the concept of a critical path. The critical path is the longest chain of dependent events. This is the single sequence of tasks whose combined required times define the minimum possible completion time for the entire set of tasks. Consider Project X represented in Figure 14. Either the sequence C-D-F or the sequence C-E-F defines how much time is required to complete the four tasks C, D, E, and F. In this case, the path C-D-F requires 18 weeks and the path C-E-F requires 15 weeks, so the critical path for the whole project includes C-D-F. The critical path for the project is denoted by the thick lines in Figure 14. Identifying the critical path is important because a delay in any of these critical tasks would result in an increase in project duration. All other paths contain some slack, meaning that a delay in one of the noncritical tasks does not necessarily create a delay for the entire project. Figure 14. shows that task D is behind schedule. Because task D is on the critical path, this delay, if not corrected, will result in a delay of the completion of the entire project.
Several software packages are available for producing Gantt charts and PERT charts; these programs can also compute the critical path.

3.2 Baseline Project Planning

The project plan is the roadmap for the remaining development effort. The plan is important in coordinating the remaining tasks and in estimating the required development resources and development time. Some measure of project planning occurs at the earliest stages of product development, but the importance of the plan is highest at the end of the concept development phase, just before significant development resources are committed. This section presents a method for creating a baseline project plan. After establishing this baseline, the team considers whether it should modify the plan to change the planned development time, budget, or project scope. The results of the concept development phase plus the project plan make up the **contract book**. It is often recommended that a contract book be used to document the project plan and the results of the concept development phase of the development process. The word contract is used to emphasize that the document represents an agreement between the development team and the senior management of the company about project goals, direction, and resource requirements. Below we discuss some of the essential elements of the project plan, i.e. the project task list, team staffing and organization, the project schedule, the project budget, and the project risk areas.

3.2.1 Project Task List

The first step in planning a project is to list the tasks which make up the project. For most product development projects, the team will not be able to list every task in detail because too much uncertainty will still exist about subsequent development activities. However, the team will be able to list its best estimate of the remaining tasks at a general level of detail.

An effective way to tackle the generation of the task list is to consider the tasks in each of the remaining phases of development. In a general development process, the phases remaining after concept development are system-level design, detail design, testing and refinement, and production. In some cases, the current effort will be very similar to a previous project. In these cases, the list of tasks from the previous project is a good starting point for the new task list. Project X was very similar to dozens of previous efforts. For this reason, the team had no trouble identifying the project tasks. (Its challenge was to complete them quickly.)

After listing all the tasks, the team estimates the effort required to complete each task. Effort is usually expressed in units of man-hours, man-days, or man-weeks depending on the size of the project. These estimates reflect the "actual working time" that members of the development team would have to apply to the task and not “elapsed calendar time". Because the speed with which a task is completed has some influence on the total amount of effort that must be applied, the estimates embody preliminary assumptions about the overall project schedule and how quickly the team will attempt to complete tasks. These estimates are typically derived from past experience or the judgment of experienced members of the development team. A task list for Project X is shown in Figure 15.

Task		Estimated Man-Weeks	Sub-totals
Concept Development	Receive and accept specification	8	24
	Concept generation / selection	16	
Detail Design	Design beta cartridges	62	110
	Produce beta cartridges	24	
	Develop testing program	24	
Testing and Refinement	Test beta cartridges	20	204
	Design production cartridges	56	
	Design mold	36	
	Design assembly tooling	24	
	Purchase assembly equipment	16	
	Fabricate molds	16	
	Debug molds	24	
	Certify cartridge	12	
Production ramp-up	Initial production run	16	16
TOTAL			354

Figure 15 Task List for Project X

3.2.2 Team Staffing and Organization

The project team is the collection of individuals who complete project tasks. Whether the team is effective depends on a wide variety of individual and organizational factors. What determines the speed with depends on several criteria, some of which predict other aspects of team performance. Among them are the following:

1. There are 10 or fewer members of the team.

2. Members volunteer to serve on the team.
3. Members serve on the team from the time of concept development until product launch.
4. Members are assigned to the team full-time.
5. Members report directly to the team leader.
6. The key functions, including at least marketing, design, and manufacturing, are on the team.
7. Members are located within conversational distance of each other.

While few teams are staffed and organized ideally, these criteria raise several key issues. How big should the team be? How should the team be organized relative to the larger enterprise? Which functions should be represented on the team? How can the development of a very large project exhibit some of the agility of a small team? There are many trade-offs to consider when considering make-up of the team and the selection needs careful assessment.

The project staffing for Project X is shown in Figure 16., where the numbers shown are approximate percentages of full time.

Person	Month:	1	2	3	4	5	6	7	8	9	10	11	12
Team Leader		100	100	100	100	100	100	100	100	100	100	100	100
Schedule Coordinator		25	25	25	25	25	25	25	25	25	25	25	25
Customer Liaison		50	50	50	50	25	25	25	25	25	25	25	25
Mechanical Designer 1		100	100	100	100	100	100	100	100	50	50	50	50
Mechanical Designer 2			50	100	100	100	100	100	100	50			
CAD Technician 1			50	100	100	100	100	100	100	100	50	50	50
CAD Technician 2					50	100	100	100	100	100	50		
Mold Designer 1		25	25	25	25	100	100	100	100	25	25	25	
Mold Designer 2						100	100	100	100				
Assembly Tool Designer		25	25	25	25	100	100	100	100	100	100	50	50
Manufacturing Engineer		50	50	100	100	100	100	100	100	100	100	100	100
Purchasing Engineer			50	50	100	100	100	100	100	100	100	100	100

Figure 16 Project staffing for Project X

3.2.3 Project Schedule

The project schedule is the merger of the project tasks and the project timeline. The schedule identifies when major project milestones are expected to occur and when each project task is expected to begin and end. The team uses this schedule to track progress and to orchestrate the exchange of materials and information between individuals. It is, therefore, important that the schedule is viewed as credible by the entire project team. The following steps are recommended to create a baseline project schedule:

1. Use the DSM or PERT chart to identify the dependencies among tasks.
2. Position the key project milestones along a timeline in a Gantt chart.
3. Schedule the tasks, considering the project staffing and other critical resources.
4. Adjust the timing of the milestones to be consistent with the time required for the tasks.

Project milestones are useful as anchor points for the scheduling activity. A common milestone includes design reviews (also called phase reviews or design gates). Because these events typically require input from almost everyone on the development team, they serve as powerful forces for integration and act as anchor points on the schedule. Once the milestones are laid out on the schedule, the tasks can be arranged between these milestones.

The Project X schedule was developed by expanding the typical project phases into a set of approximately 100 tasks. The major milestones were the concept approval, the testing of beta prototype cartridges, the trade show demonstration, and production ramp-up. Relationships among these activities and the critical path were documented using a combined PERT /Gantt chart.

3.2.4 Project Budget

Budgets are customarily represented with a simple spreadsheet, although many companies have standard budgeting forms for requests and approvals. The major budget items are staff, materials and services, project-specific facilities, and spending on outside development resources.

For most projects, the largest budget item is the cost of staff. For Project X, personnel charges made up 80 percent of the total budget. The personnel costs can be derived directly from the staffing plan by applying the loaded salary rates to the estimated time commitments of the staff on the project. Loaded salaries include employee benefits and overhead and are typically between two and three times the actual salary of the team member. Many companies use only one or two different rates to represent the cost of the people on a project. Average staff costs for product development projects range from £1,000 to £5,000 per person-week. For Project X, assuming an average cost of £3,000 per person-week, the total cost for the 354 person-weeks of effort would be £1,062,000.

Early in the development project, uncertainty of both timing and costs are high, and the forecasts may only be accurate within 30 to 50 percent. In the later stages of the project the program uncertainty is reduced to perhaps 5 percent to 10 percent. For this reason, some margin should be added to the budget as a contingency. A summary of the Project X budget is shown in Figure 17.

Item		**Amount (£)**
Staff salaries (354 man-weeks @ £3,000 per week)		1,062,000
Materials and Services		125,000
Prototype Molds		75,000
Outside Resources, Consultants		25,000
Travel		50,000
	Subtotal	1,337,000
	Contingency (20%)	267,400
	Total	**1,604,000**

Figure 17 Summary Budget for Project X

3.2.5 Project Risk Plan

Projects rarely proceed exactly according to plan. Some of the deviations from the plan are minor and can be accommodated with little or no impact on project performance. Other deviations can cause major delays, budget overruns, poor product performance, or high manufacturing costs. Often the team can assemble, in advance, a list of what might possibly go wrong, that is, the areas of risk for the project.

After identifying each risk, the team can prioritize the risks. To do so, some teams use a scale combining severity and likelihood of each risk. A complete risk plan also includes a list of actions the team will take to minimize the risk. In addition to pushing the team to work to minimize risk, the explicit prioritization of risk during the project planning activity helps to minimize the number of surprises the team will have to communicate to its senior management later in the project. The risk plan for Project X is shown in Figure 18., where the production and tooling costs are accounted for as manufacturing costs rather than as part of the development project budget.

Risk	Risk Level	Actions to Minimise Risk
Change in customer specification.	Moderate	• Involve the customer in the process of refining the specification. • Work with the customer to estimate time and cost penalties of changes.
Poor feeding characteristics of cartridge design.	Low	• Build early functional prototype from machined parts. • Test prototype in microfilm machine.
Delays in mold-making shop.	Moderate	• Reserve 25% of shop capacity for May to July.
Mold problems require rework of mold.	High	• Involve mold maker and mold designer in the part design. • Perform mold filling computer analysis. • Choose materials at the end of concept development phase.

Figure 18 Risk Plan for Project X

3.2.6 Modifying the Baseline Plan

The baseline project plan embodies assumptions about how quickly the project should be completed, about the performance and cost goals for the product, and about the resources to be applied to the project. After completing a baseline plan, the team should consider whether some of these assumptions should be revisited. Specifically, the team can usually choose to trade off development time, development cost, product manufacturing cost, product performance, and risk. For example, a project can sometimes be completed more quickly by spending more money. Some of these trade-offs can be explored quantitatively using various economic analysis techniques. The team may also develop contingency plans in case certain risks cannot be overcome. The most common desired modification to the baseline plan is to compress the schedule.

3.2.7 Accelerating Projects

Product development time is often the dominant concern in project planning and execution. Most of the guidelines for accelerating product development presented here are applicable at the project planning stage, although a few can be applied throughout a development project. Accelerating a project before it has begun is much easier than trying to expedite a project that is already underway.

The first set of guidelines applies to the project as a whole:

Start the project early. Saving a month at the beginning of a project is just as helpful as saving a month at the end of a project, yet teams often work with little urgency before development formally begins. For example, the meeting to approve a project plan and review a contract book is often delayed for weeks because of difficulty in scheduling a meeting with senior managers. This delay at the beginning of a project costs exactly as much time as the same delay during production ramp-up. The easiest way to complete a project sooner is to start it early.

Manage the project scope. There is a natural tendency to add additional features and capabilities to the product as development progresses. This is sometimes called ''feature creep" or "creeping elegance” and in time-sensitive contexts it may result in an elegant product without a market. Disciplined teams and organisations "freeze the design" and leave incremental improvements for the next generation of the product.

Facilitate the exchange of essential information. As shown in the DSM representation, a tremendous amount of information must be transferred within the product development team. Every task has one or more internal customers for the information it produces. For small teams, frequent exchange of information is quite natural and is facilitated by team meetings and co-location of team members. Larger teams may require more structure to promote rapid and frequent information exchange. Blocks of coupled tasks revealed by the DSM identify the specific needs for intensive information exchange. Computer networks and collaboration software tools can facilitate regular information transfer within large and dispersed product development teams.

The second set of guidelines is aimed at decreasing the time required to complete the tasks on the critical path. These guidelines arise from the fact that the only way to reduce the time required to complete a project is to shorten the critical path. Note that a decision to allocate additional resources to shortening the critical path should be based on the value of accelerating the entire project. For some projects, time reductions on the critical path can be worth hundreds of thousands, or even millions, of ponds per week.

Complete individual tasks on the critical path more quickly. The benefit of recognizing the critical path is that the team can focus its efforts on this vital sequence of tasks. The critical path generally represents only a small fraction of the total project effort, and so additional spending on completing a critical task more quickly can usually quite easily be justified. Sometimes completing critical tasks more quickly can be achieved simply by identifying a task as critical so that it gets special attention, starts earlier, and is not interrupted. Note that the accelerated completion of a critical task may cause the critical path to shift to include previously noncritical tasks.

Aggregate safety times. The estimated duration of each task in the project generally includes some amount of "safety time." This time accounts for the many normal but unpredictable delays which occur during the execution of each task. Common delays include: waiting for information and approvals, interruptions from other tasks or projects, and tasks being more difficult than anticipated. It has been estimated that built-in safety doubles the nominal duration of tasks. Although safety time is added to the expected task duration to account for random delays, these estimates become targets during execution of the tasks, which means that tasks are rarely completed early and many tasks overrun. It is recommended to remove the safety time from each task along the critical path and aggregating all the safety time from the critical path into a single project buffer placed at the end of the project schedule. Because the need to and disposal or recycling. Designers use this process to help critique their products. LCAs can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

The goal of LCA is to compare the full range of environmental effects assignable to products and services by quantifying all inputs and outputs of material flows and assessing how these material flows affect the environment. This information is used to improve processes, support policy and provide a sound basis for informed decisions.

The term ***life cycle*** refers to the notion that a fair, holistic assessment requires the assessment of raw-material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence.

There are two main types of LCA. Attributional LCAs seek to establish (or attribute) the burdens associated with the production and use of a product, or with a specific service or process, at a point in time (typically the recent past). Consequential LCAs seek to identify the environmental consequences of a decision or a proposed change in a system under study (oriented to the future), which means that market and economic implications of a decision may have to be considered. Social LCA is under development **Error! Reference source not found.**as a different approach to life cycle thinking intended to assess social implications or potential impacts. Social LCA should be considered as an approach that is complementary to environmental LCA.

The procedures of life cycle assessment (LCA) are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. (ISO 14044 replaced earlier versions of ISO 14041 to ISO 14043.) Green House Gas (GHG) product life cycle assessments can also comply with specifications such as Publicly Available Specification (PAS) 2050 and the GHG Protocol Life Cycle Accounting and Reporting Standard.

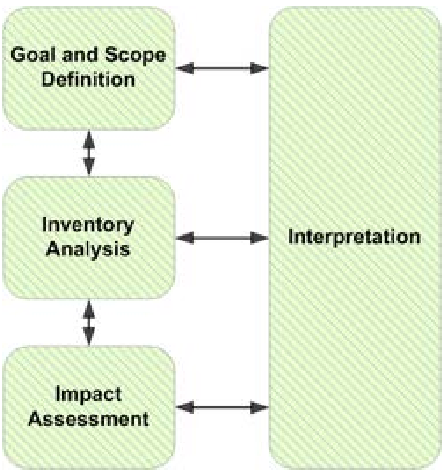

Figure 23 Illustration of LCA Phases

According to the ISO 14040 and 14044 standards, a Life Cycle Assessment is carried out in four distinct phases as illustrated in Figure 23. The phases are often interdependent in that the results of one phase will inform how other phases are completed.

4.3.1 Goal and scope

An LCA starts with an explicit statement of the goal and scope of the study, which sets out the context of the study and explains how and to whom the results are to be communicated. This is a key step and the ISO standards require that the goal and scope of an LCA be clearly defined and consistent with the intended application. The goal and scope document therefore includes technical details that guide subsequent work, as follows:

- **The functional unit**, which defines what precisely is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related. Further, the functional unit is an important basis that enables alternative goods, or services, to be compared and analysed. So, to explain this a functional system which is inputs, processes and outputs contains a functional unit, that fulfils a function, for example paint is covering a wall, making a functional unit of $1m^2$ covered for 10 years. The functional flow would be the items necessary for that function, so this would be a brush, tin of paint and the paint itself.
- **The system boundaries**; which are delimitations of which processes that should be included in the analysis of a product system.
- **Any assumptions and limitations**;
- **The allocation methods** used to partition the environmental load of a process when several products or functions share the same process; allocation is commonly dealt with in one of three ways: system expansion, substitution and partition. Doing this is not easy and different methods may give different results, and
- **The impact categories** chosen for example human toxicity, smog, global warming, eutrophication (over-rich in nutrients).

4.3.2 Life Cycle Inventory

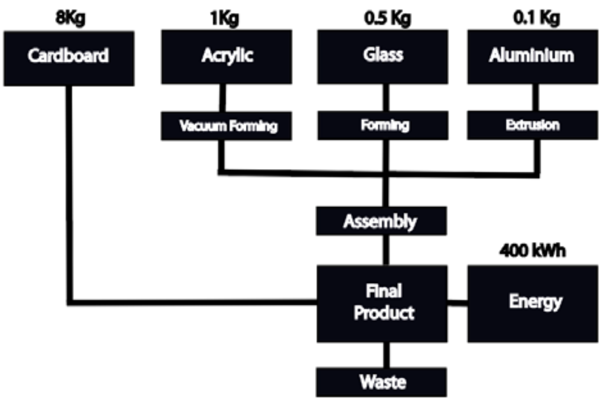

Figure 24 Example of a Life Cycle Inventory (LCI) diagram

Life Cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. The flow model is typically illustrated with a flow chart that includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain (referred to as inputs from the techno-sphere).

The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can be made already at this stage. The result of the inventory is an LCI which provides information about all inputs and outputs in the form of elementary flow to and from the environment from all the unit processes involved in the study.

Inventory flows can number in the hundreds depending on the system boundary. For product LCAs at either the generic (i.e., representative industry averages) or brand-specific level, that data is typically collected through survey questionnaires. At an industry level, care must be taken to ensure that questionnaires are completed by a representative sample of producers, leaning toward neither the best nor the worst, and fully representing any regional differences due to energy use, material sourcing or other factors. The questionnaires cover the full range of inputs and outputs, typically aiming to account for 99% of the mass of a product, 99% of the energy used in its production and any environmentally sensitive flows, even if they fall within the 1% level of inputs.

One area where data access is likely to be difficult is flows from the techno-sphere. The techno-sphere is more simply defined as the man-made world. Considered by geologists as secondary resources, these resources are in theory 100% recyclable; however, in a practical sense, the primary goal is salvage. For an LCI, these techno-sphere products (supply chain products) are those that have been produced by man and unfortunately those completing a questionnaire about a process which uses a man-made product to an end will be unable to specify how much of a given input they use. Typically, they will not have access to data concerning inputs and outputs for previous production processes of the product. The entity undertaking the LCA must then turn to secondary sources if it does not already have that data from its own previous studies. National databases or data sets that come with LCA-practitioner tools, or that can be readily accessed, are the usual sources for that information. Care must then be taken to ensure that the secondary data source properly reflects regional or national conditions.

LCI methods include:

- Process LCA
- Economic Input Output LCA
- Hybrid Approach

4.3.3 Life Cycle Impact Assessment (LCIA)

Inventory analysis is followed by impact assessment. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. Classical life cycle impact assessment (LCIA) consists of the following mandatory elements:

- selection of impact categories, category indicators, and characterization models;
- the classification stage, where the inventory parameters are sorted and assigned to specific impact categories; and

- impact measurement, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total.

In many LCAs, characterization concludes the LCIA analysis; this is also the last compulsory stage according to ISO 14044:2006. However, in addition to the above mandatory LCIA steps, other optional LCIA elements – normalisation, grouping, and weighting – may be conducted depending on the goal and scope of the LCA study. In normalization, the results of the impact categories from the study are usually compared with the total impacts in the region of interest, the U.K. for example. Grouping consists of sorting and possibly ranking the impact categories. During weighting, the different environmental impacts are weighted relative to each other so that they can then be summed to get a single number for the total environmental impact. ISO 14044:2006 generally advises against weighting, stating that “weighting, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public”. This advice is often ignored, resulting in comparisons that can reflect a high degree of subjectivity because of weighting.

Life cycle impacts can also be categorized under the several phases of the development, production, use, and disposal of a product. Broadly speaking, these impacts can be divided into "First Impacts," use impacts, and end of life impacts. "First Impacts" include extraction of raw materials, manufacturing (conversion of raw materials into a product), transportation of the product to a market or site, construction/installation, and the beginning of the use or occupancy. Use impacts include physical impacts of operating the product or facility (such as energy, water, etc.), maintenance, renovation and repairs (required to continue to use the product or facility). End of life impacts include demolition and processing of waste or recyclable materials.

4.3.4 Interpretation

Life Cycle Interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study. According to ISO 14040:2006, the interpretation should include:

- identification of significant issues based on the results of the LCI and LCIA phases of an LCA;
- evaluation of the study considering completeness, sensitivity and consistency checks; and
- conclusions, limitations and recommendations.

A key purpose of performing life cycle interpretation is to determine the level of confidence in the final results and communicate them in a fair, complete, and accurate manner. Interpreting the results of an LCA is not as simple as "3 is better than 2, therefore Alternative A is the best choice"! Interpreting the results of an LCA starts with understanding the accuracy of the results, and ensuring they meet the goal of the study. This is accomplished by identifying the data elements that contribute significantly to each impact category, evaluating the sensitivity of these significant data elements, assessing the completeness and consistency of the study, and drawing conclusions and recommendations based on a clear understanding of how the LCA was conducted and the results were developed. More specifically, the best alternative is the one that the LCA shows to have the least cradle-to-grave environmental negative impact on land, sea, and air resources.

4.4 LCA uses

Based on a survey of LCA practitioners carried out in 2006 LCA is mostly used to support business strategy (18%) and R&D (18%), as input to product or process design (15%), in education (13%) and for labelling or product declarations (11%). LCA will be continuously integrated into the built environment as tools such as the European ENSLIC Building project guidelines for buildings or developed and implemented, which provide practitioners guidance on methods to implement LCI data into the planning and design process.

Major corporations all over the world are either undertaking LCA in house or commissioning studies, while governments support the development of national databases to support LCA. Of note is the growing use of LCA for ISO Type III labels called Environmental Product Declarations, defined as "quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information". These third-party certified LCA-based labels provide an increasingly important basis for assessing the relative environmental merits of competing products. Third-party certification plays a major role in today's industry. Independent certification can show a company's dedication to safer and environmental friendlier products to customers and NGOs.

LCA also has major roles in environmental impact assessment, integrated waste management and pollution studies.

4.5 Data analysis

A life cycle analysis is only as valid as its data; therefore, it is crucial that data used for the completion of a life cycle analysis are accurate and current. When comparing different life cycle analyses with one another, it is crucial that equivalent data are available for both products or processes in question. If one product has a much higher availability of data, it cannot be justly compared to another product which has less detailed data.

There are two basic types of LCA data – unit process data and environmental input-output data (EIO), where the latter is based on national economic input-output data. Unit process data are derived from direct surveys of companies or plants producing the product of interest, carried out at a unit process level defined by the system boundaries for the study.

Data validity is an ongoing concern for life cycle analyses. Due to globalisation and the rapid pace of research and development, new materials and manufacturing methods are continually being introduced to the market. This makes it both very important and very difficult to use up-to-date information when performing an LCA. If an LCA's conclusions are to be valid, the data must be recent; however, the data-gathering process takes time. If a product and its related processes have not undergone significant revisions since the last LCA data was collected, data validity is not a problem. However, consumer electronics such as cell phones can be redesigned as often as every 9 to 12 months, creating a need for ongoing data collection.

The life cycle considered usually consists of several stages including: materials extraction, processing and manufacturing, product use, and product disposal. If the most environmentally harmful of these stages can be determined, then impact on the environment can be efficiently reduced by focusing on making changes for that phase. For example, the most energy-intensive life phase of an airplane or car is during use due to fuel consumption. One of the most effective ways to increase fuel efficiency is to decrease vehicle weight, and thus, car and airplane manufacturers can decrease environmental impact in a significant way by replacing heavier materials with lighter ones such as aluminium or carbon fibre-reinforced elements. The reduction during the use phase should be more than enough to balance additional raw material or manufacturing cost.

Data sources are typically large databases, it is not appropriate to compare two options if different data sources have been used to source the data. Calculations for impact can then be done by hand, but it is more usual to streamline the process by using software. This can range from a simple spreadsheet, where the user enters the data manually to a fully automated program, where the user is not aware of the source data.

4.6 Variants

4.6.1 Cradle-to-grave

Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave'). For example, trees produce paper, which can be recycled into low-energy production cellulose (fibre-ised paper) insulation, then used as an energy-saving device in the ceiling of a home for 40 years, saving 2,000 times the fossil-fuel energy used in its production. After 40 years the cellulose fibres are replaced and the old fibres are disposed of, possibly incinerated. All inputs and outputs are considered for all the phases of the life cycle.

4.6.2 Cradle-to-gate

Cradle-to-gate is an assessment of a *partial* product life cycle from resource extraction (*cradle*) to the factory gate (i.e., before it is transported to the consumer). The use phase and disposal phase of the product are omitted in this case. Cradle-to-gate assessments are sometimes the basis for environmental product declarations (EPD) termed business-to-business EDPs. One of the significant uses of the cradle-to-gate approach compiles the life cycle inventory (LCI) using cradle-to-gate. This allows the LCA to collect all the impacts leading up to resources being purchased by the facility. They can then add the steps involved in their transport to plant and manufacture process to more easily produce their own cradle-to-gate values for their products.

4.6.3 Cradle-to-cradle or closed loop production

Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. It is a method used to minimize the environmental impact of products by employing sustainable production, operation, and disposal practices and aims to incorporate social responsibility into product development. From the recycling process originate new, identical products (e.g., asphalt pavement from discarded asphalt pavement, glass bottles from collected glass bottles), or different products (e.g., glass wool insulation from collected glass bottles).

Allocation of burden for products in open loop production systems presents considerable challenges for LCA. Various methods, such as the avoided burden approach have been proposed to deal with the issues involved.

4.6.4 Gate-to-gate

Gate-to-gate is a partial LCA looking at only one value-added process in the entire production chain. Gate-to-gate modules may also later be linked in their appropriate production chain to form a complete cradle-to-gate evaluation.

4.6.5 Well-to-wheel

Well-to-wheel is the specific LCA used for transport fuels and vehicles. The analysis is often broken down into stages entitled "well-to-station", or "well-to-tank", and "station-to-wheel" or "tank-to-wheel", or "plug-to-wheel". The first stage, which incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, and is called the "upstream" stage, while the stage that deals with vehicle operation itself is sometimes called the "downstream" stage. The well-to-wheel analysis is commonly used to assess total energy consumption, or the energy conversion efficiency and emissions impact of marine vessels, aircraft and motor vehicles, including their carbon footprint, and the fuels used in each of these transport modes.

The well-to-wheel variant has a significant input on a model developed by the Argonne National Laboratory. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was developed to evaluate the impacts of new fuels and vehicle technologies. The model evaluates the impacts of fuel use using a well-to-wheel evaluation while a traditional cradle-to-grave approach is used to determine the impacts from the vehicle itself. The model reports energy use, greenhouse gas emissions, and six additional pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micrometre (PM10), particulate matter with size smaller than 2.5 micrometre (PM2.5), and sulphur oxides (SOx).

4.6.6 Economic input–output life cycle assessment

Economic input–output LCA (EIOLCA) involves use of aggregate sector-level data on how much environmental impact can be attributed to each sector of the economy and how much each sector purchases from other sectors. Such analysis can account for long chains (for example, building an automobile requires energy, but producing energy requires vehicles, and building those vehicles requires energy, etc.), which somewhat alleviates the scoping problem of process LCA; however, EIOLCA relies on sector-level averages that may or may not be representative of the specific subset of the sector relevant to a particular product and therefore is not suitable for evaluating the environmental impacts of products. Additionally, the translation of economic quantities into environmental impacts is not validated.

4.6.7 Ecologically based LCA

While a conventional LCA uses many of the same approaches and strategies as an Eco-LCA, the latter considers a much broader range of ecological impacts. It was designed to provide a guide to wise management of human activities by understanding the direct and indirect impacts on ecological resources and surrounding ecosystems. Developed by Ohio State University Centre for resilience, Eco-LCA is a methodology that quantitatively considers regulating and supporting services during the life cycle of economic goods and products. In this approach services are categorized in four main groups: supporting, regulating, provisioning and cultural services.