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A Planning & Scheduling System for the LHC Project

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Abstract

The purpose of this paper is to present modern ways to manage time, resources and progress in a large-scale project. Over the last ten years, new project management techniques and tools have appeared such as concurrent engineering, Continuous Acquisition Lifecycle Support (CALS) and Engineering Data Management System (EDMS). The world downturn of the early 90s influenced project management: increasing constraints on time and budget and more external direction on spending that, for example, requires sophisticated sub-contracting practises. However, the evolution of the software and hardware market makes project control tools cheaper and easier to use. All project groups want to have their scope of work considered as complete projects and to control them themselves. This has several consequences on project staff behaviour concerning project control, and has to be taken into account in every planning process designed today. The system described will be at the heart of the planning and scheduling procedures issued for the Large Hadron Collider (LHC), a ten-year project starting at the beginning of 1995, at CERN in Switzerland.

Keywords: project planning, project scheduling, work breakdown structure, interface management, suppliers and sub-contractors' requirements, risk assessment, Microsoft Project, PSDI P/X.

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1. Introduction

1.1. Time, Cost and Performance

These three dimensions define a project — when it will finish, at what cost in money and resources and what the output will be.

Time is a global, impartial performance indicator. It is an incontestable tool to find a consensus between the different actors and thus to manage the streamlining process — scheduling activities so that they take the least time. Focusing on time eases the description of the logistics and makes them easier to control. Identification of the project milestones and fixing them with the various actors is a vital issue: managing these milestones was the key to the timely completion of the LEP project[1].

Time management should aim at getting short lead times[2], which bring flexibility, cost reduction and quality.

- Changes to specifications are easier and much cheaper to make during design than after production starts. Short lead times increase **flexibility** by extending the length of the design phase.
- **Reduce cost** by avoiding buffer stocks (with their associated early payments) and by reducing production time.
- Improve **quality** by increasing the time available to design the component and by reducing the risk of damage to components in storage.

The LHC project has a specific constraint: along its life cycle, income will be constant while expenditure will have a gaussian distribution. Plans and schedules will help the project director and financial controllers to optimise resource usage and the rate of progress to make income and expenditure balance.

One takes the best available estimates for the cost of each activity to calculate future expenditure. These estimates are not static. They improve from initial guesses, through the results of a price enquiry, the tender price, to the contracted cost. The contracted cost may change in response to fluctuations in raw material prices and to amendments to the contract. This constant change in costs requires a dynamic link between the purchasing, financial and planning systems.

It is usually possible to reduce resources to costs. The materials budget, for example, may be spent to recruit people on service contracts. Here one has the possibility to trade money for resources and, possibly, time. In contrast, where the limit to the resource is not the amount of money available, it is not possible to equate resources with costs. An example of this situation is the number of staff directly employed by CERN. Then it is useful to consider resources by availability.

Financial accounting procedures force us to consider the material budget explicitly, whereas staff and equipment limitations can be implicit in estimates of the time an activity should take. However, by making these resources explicit as well, one can both forecast the staff requirements and equipment needs and see the effects of changing availability of these resources. These are exceedingly useful and desirable goals.

One of the inputs to the planning process is the *action plan*. This is the highest level definition of the project, created by the project management and other interested parties — these include, for the LHC, future LHC physicists, those using LEP now, and the CERN council. The action plan is a summary of the project including the dates of major events and the purpose of the project. At the end of the project the LHC should work as specified. There are other indicators of performance, for example the quality of work, the safety of the system and the impact on to the environment.

The essence of quality assurance is *describing what must be done and doing what has been described.* This applies both to the planning process and to the planning schedules. The planning process will describe how to produce and follow-up schedules. The process must be followed by all involved. The schedules will in turn describe how to build each part of the LHC and must be followed. If this sounds authoritarian, remember the people affected by the process and the plans will help to create them.

1.2. A planning system

The CERN Council approved the LHC project at the end of 1994. A planning system that meets (and does not exceed) the requirements of those who have to build the LHC is required. The most important goal is to build a working accelerator on time. This requires co-ordination of the technical groups that will build the LHC. To co-ordinate the project requires an overall view, which can only be achieved by collecting and summarising detailed information, which in turn is possible only if the information is coherent across the whole project. There is also a desire to maximise the freedom of the technical groups to organise and manage their work.

The first tasks in a large project are to define the *planning system*, and the Product, Assembly, Work and Organisational Breakdown Structures[2] (PBS, ABS, WBS, OBS respectively). The LHC planning system has three components: the **people** who will do the planning, a **process** that specifies what they have to do to manage time and resources, and the **software tools** and **hardware** that help the planners to apply the process. The planning system and the breakdown structures make a framework in which work can proceed.

1.3. In this paper

Many discussions of project management centre on how to start the project, with very little attention paid to how the project will run. This paper aims to address both. Above all, this paper presents a very pragmatic approach to planning and scheduling applied to one-of-a-kind large-scale projects such as the LHC.

This paper has the following structure.

- Some planning and scheduling approaches are presented and their advantages discussed — the one selected identifies and decouples three levels of planning.
- Procedures for project planning are outlined as a basis for discussing and creating detailed procedures.
- The selection of tools to aid the planner is considered within the context of the project, particularly the desire to enable all groups to participate in the planning and to make connections to centralised databases during the installation phase.
- Finally, there is an action plan for implementing the planning system in time to test it on the prototype dipole magnet sub-project.

2. Themes

2.1. Techniques

In the past, traditional academic approaches to project planning and scheduling focused on algorithmic techniques. Deterministic networking techniques such as Program Evaluation & Review Technique (PERT) or Critical Path Method (CPM) were developed in the sixties, resource allocation optimisation algorithms in the early seventies, probabilistic networking methods in the late seventies, and Program Analysis, Control and Evaluation (PACE) more recently. When applied to large-scale projects, all these modelling techniques had in common huge calculation requirements available only on main-frame computers, indeed one of the first uses of computers was to perform such calculations!

The following model of a project lifecycle[3] is interesting because it reflects clearly the inputs and outputs attached to one-of-a-kind industrial projects. It emphasises the close connections that exist between time and levels of conceptualisation and materialisation.

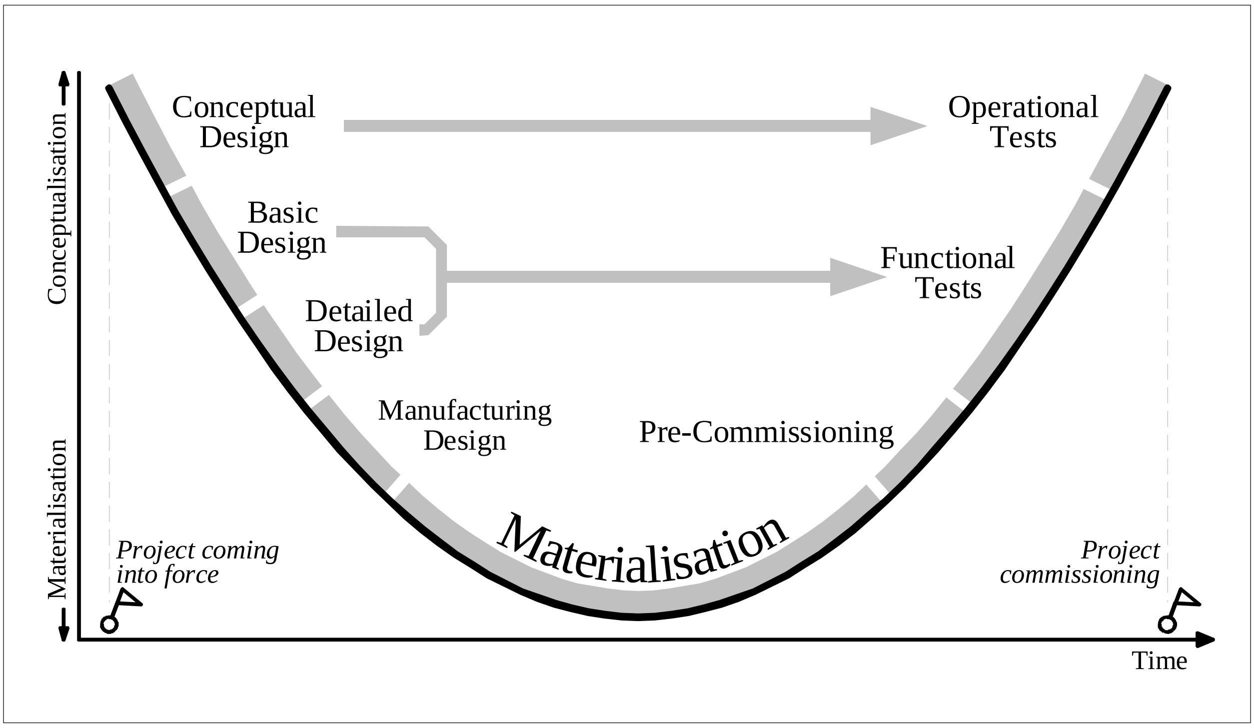

Figure 1 **: The Project Lifecycle**

There are many studies on these and other aspects of project control, for example on the human side of project management and time, resource and progress control using software tools. There are fewer studies into how to fit these ideas together into a system for project management.

2.2. Managing Risk

The LHC project involves strategic, technical and economic elements. Dealing with risk is important. There are two ways of implementing risk management: a qualitative approach, and a quantitative method.

The quantitative method is based on Monte-Carlo simulations. A statistical distribution of task duration is attached to each activity. This requires feed-back from previous projects for each type of task. For speculative Research and Development projects such as the LHC the quantitative approach is inefficient: costly and with limited results.

The qualitative approach consists of identifying the risks at each stage of the project. With the risks identified, one may simulate multiple scenarios, creating a schedule for each, and assessing the risk on the basis of these simulations (what-if analyses). Planning co-ordinators can contribute a great deal to this process. Placing *risk limitation floats* between *work packages*[2] helps to reduce propagation of delays.

2.3. Levels, Phases and Decoupling

The project management must have an overview of the project. They also want the people who build LHC to make their own plans, in the belief that this will maximise commitment to the project. These ideas lead to two notions: a hierarchy of *levels* in the planning system and a *time grid*. Having a hierarchy of levels allows the management to concentrate on the major milestones of the project. This leaves the technical groups to plan how to achieve them. From the major milestones, time slots will be developed and subdivided to provide a grid in which to schedule the work packages. This grid, and the major milestones, establish *control points* that the management can concentrate on. These principles allow both the co-ordination of work across groups and the maximum freedom of action for each group.

There are two ways to set up the planning process: single-network planning and multi-level planning. In a single network all activities are linked and a change to one has the potential to affect all others. Work packages in multi-level systems are decoupled and changes to activities affect only the work package they are in.

2.3.1. Single-network planning

In this traditional approach to planning, the project as a whole is networked and scheduled when the WBS is available. At the beginning of the project the first activities are well defined, both the estimates of duration and the links to other activities are known. Activities a long way in the future are represented by loosely linked summary tasks. With time, medium term tasks become short term tasks and the WBS can be updated and thus the network and the schedule.

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- There is a unique network to manage.
- This is the planning process used on small projects.
- Many *limited* project control software systems are designed to run under this paradigm.

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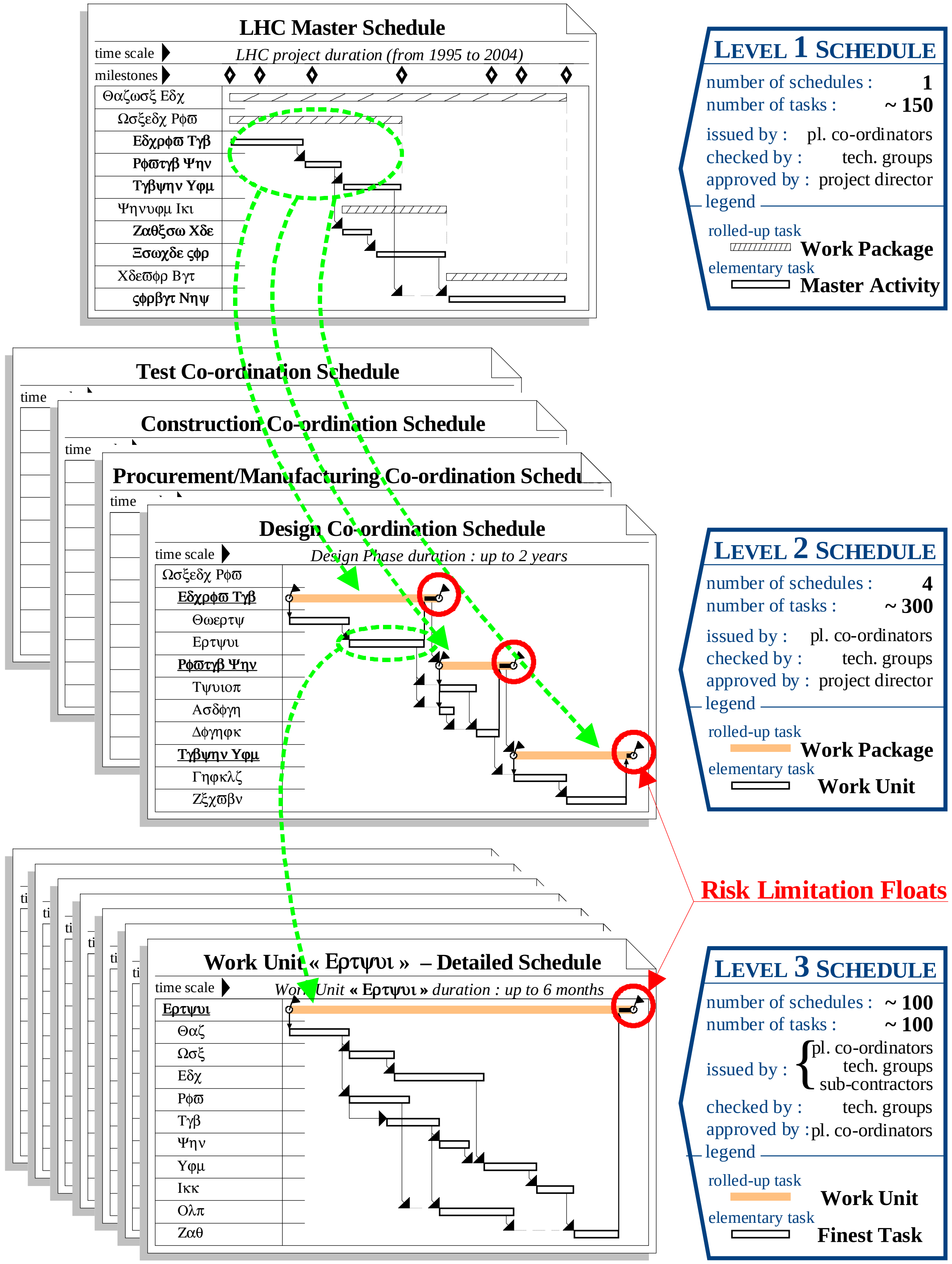
- This type of schedule must be updated very frequently.
- When scheduling, the planned duration given to a task is mean value. In most cases the actual duration is longer or shorter, rarely equal to the planned duration. The consequence is that the network changes frequently, each time it is recalculated. From one week to the next group leaders must re-optimise their remaining work: *relevelling* their resources, *re-estimating* task duration, *reconsidering* the logical links to avoid postponing the target milestones. On a large-scale project, this requires much energy from lead engineers with insignificant results, which results in a resistance to engage in formal planning.
- This system is quite efficient at the early stage of the project, but it becomes more and more complex with time. This leads to project staff starting to use *daily remaining work estimates* instead. And it is up to the project management to convince people involved with planning the project to keep using such a huge network .
- Reporting the project performance is more difficult. The status date is found on the updated revision of the schedule, and not on the base-line version.
- It is better to distribute risk limitation floats throughout the project, but with this system float tends to bunch at the end of the project.

2.3.2. Multi-level planning

To avoid these problems one can use multi-level planning. Corporate planners, for example, use three levels. The highest level is the strategic plan owned by the company directorate, which contains the company goals for the long term, three to five years. At the intermediate level are the tactical plans, owned by the divisions of the company. Each manager plans the activity of the division for a medium term period, up to two years. All tactical plans must fit into the strategic plan and with the plans of the other divisions. The operational plans add detail to the tactical plans for the coming two or three months. In planning terms, these levels are called *master*, *co-ordination* and *detailed*.

Applied to a large-scale project such as the LHC, the top level is the *master schedule*. It covers the whole duration of the project from conceptual design to final commissioning. The master schedule may contain up to 150 tasks and milestones and is issued before the project start-up. It may be modified occasionally, to reflect changes in the scope of the work and new environmental constraints.



Note : a Technical Group Level 3 Schedule can detail up to 5 *Work Units.*

Figure 2 : **Schedule Consolidation between the Master Schedule and Co-ordination Levels**

At the second level there are four *co-ordination schedules*. Each covers one of the major phases of the project: the *design co-ordination schedule,* the *procurement & manufacturing co-ordination schedule,* the *construction co-ordination schedule,* and the *test co-ordination schedule*. The purpose of these schedules is to co-ordinate efficiently the work of technical groups.

The co-ordinators will consolidate these schedules into the master schedule using the WBS. They will ensure that there is a risk limitation float between each schedule. Co-ordination level schedules may be actualised[1] at most three times a year. The elementary activity of the co-ordination schedule is the work unit.

At the third level, the *detailed schedules* contain *detailed tasks.* The aims of detailed schedules issued by technical groups, sub-contractors and suppliers are: to determine that the resources (for example staff, equipment or facilities) required to achieve the tasks are available; and that the work to perform is feasible within the time constraints identified in the co-ordination schedule. These schedules, since they are internal to the groups and decoupled from other groups' schedules, may be actualised as frequently as required.

The planning co-ordinators may sometimes need more tasks than fit naturally into a co-ordination schedule. A *zoom schedule* focuses on critical tasks and a *sharing resource schedule* allows sharing of resources, for example a drawing office, amongst several groups.

When consolidated (following the WBS) these detailed schedules must fit within the corresponding work unit of the co-ordination schedule, preferably with a risk limitation float before the next work unit.

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- Risk limitation floats are distributed all along the project life cycle, in between work packages. The result of this is that activities scheduled several years in advance are not constantly moved around by trivial day-to-day changes. Thus technical group leaders can schedule resource usage in the short and medium term with greater certainty.
- Actual and expected[2] dates and duration are monitored besides planned dates. This gives a more accurate and stable view of the performance of the project.
- At the early stages of speculative projects it is impossible to have an accurate view of the whole. Setting intermediate level milestones has a beneficial effect on peoples' work — helping them to finish on time and within the budget for the level of quality required.
- This planning process has been well tried by major engineering companies involved in large-scale projects.

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- There are many schedules and sub-networks to manage: the planning team must be organised for this.
- The planning and scheduling software must be designed or selected or adapted to work with levels, which precludes the use of many software packages.
- A limited degree of freedom (defined by the WBS) is given to the project staff to contribute to the planning and scheduling of the project.
- The project management will need to ensure that the strategic milestones are met to make this planning process efficient and credible.

This concept of dividing the target into intermediate goals, even if it seems hazy in terms of networking and interface monitoring, is much more efficient in term of risk limitation and project staff involvement. The LHC planning process fits this multi-level, decoupled method well.

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[1] *Actualising* a shedule means to change the schedule in response to changed requirements or external condition. This is distinct from *following-up* a schedule, when progress is recorded on the existing schedule.

[2] An activity has a date when it is expected to start; the actual date it starts is recorded; if there is a difference between planned and actual then the expected finish date will be different to that planned.

2.4. People involved in planning LHC

There will be many people involved in planning LHC. They have differing needs and requirements, but fortunately fall into a small number of identifiable groups. Their requirements will change throughout the project, in which one may distinguish two phases: start-up, and follow-up.

a) During the start-up phase, the **project management** will have to establish the master schedule — that is, the strategic goals and major milestones of the project. These control points will constrain the planning of everyone. During the follow-up phase, they will require reports of events that may affect the control points.

b) The **planning co-ordinators** will assist the project management in the start-up phase to establish the master and co-ordination level plans for the project. Throughout the project they will maintain these plans, they will bring scheduling and resource conflicts between the various technical groups to the attention of those involved and work to resolve them. They will produce reports and risk analyses and bring to the attention of the management circumstances that may affect the control points. They will also produce and distribute progress reports and charts showing the state of the project throughout the follow-up phase.

c) During the start-up phase the **technical groups** will help the management to establish the control points of the project. The main activity in all phases is to establish detailed plans (level 3 schedules) for the implementation of LHC. They may also actively manage their resource requirements and report progress, but in some cases these functions will devolve onto the planning co-ordinators.

d) The **external collaborators** and **contractors** will establish detailed plans for their areas of work and report progress. Contractors shall have limited and strictly controlled access to the central planning data.

e) **Cost estimators**, at the start of the project**,** and **financial controllers** throughout the project, want to forecast the cost of work over a given period and take actions, for example accelerating or delaying work or payments, to keep expenditure within the available budget. This is a complex task, during which they must track increasingly accurate estimates of the cost of an activity and finally post the actual cost. They will need to analyse expenditure by country to fulfil the terms of the "Fair Return" policy, and after the end of the project they will want to asses the financial performance.

2.5. Communication between Groups

It is essential in a project the size of LHC that all know the aims of the project and the current situation. Technical groups will be dependent not only on other groups at CERN, but on the work of laboratories and firms throughout the world. It is therefore essential that there is a central repository of information on the progress of the project, and the need for a central planning group to manage it.

Here lies the incentive for the technical groups to share their plans. The planning co-ordinators will add value to the information by making links to other work packages, adding resource information and by collecting and summarising the plans of all involved and then making these summaries available to the groups. The sharing of information becomes part of the planning process rather than a feature of the planning software. There are two mechanisms for disseminating information about the LHC project. The first is the traditional one of face-to-face communication, the other is electronic.

The central planning team will work closely with management and in a tight loop with the technical groups. They will ensure that a coherent, global view of the project is available to management and technical groups. The emphasis here is working together, first to plan and then to implement the plans. In this situation, where the aim is to keep people working on the same project, and to see and avert potential problems, there is no better method of transmitting information than by personal contact, both in formal and informal situations.

For the transmission of the finer details of the project, or to those people geographically remote from CERN, and to those not involved directly in the planning effort but interested in a global view of the project, the planning co-ordinators will produce reports and charts, showing the current situation, at frequent intervals. These will be made available to all, as text and images, using the World Wide Web.

3. The Planning Process

3.1. Prerequisites

The project's action plan, specifying strategic time slots and major milestones has already been defined and awaits approval. The planning phase starts by defining the Work Breakdown Structure (WBS), which depends on the PBS and the ABS[2] which are not complete. The master schedule is being defined. This paper must also be approved before defining the planning process in detail.

3.2. WBS definition[2] [4] [5] [6]

The WBS contains all elements necessary to complete the project: all the components of the LHC and everything necessary to assemble them. It is the basis of quality control, because this complete decomposition ensures that everything that must be done is known; nothing can be forgotten. The WBS illustrates how each piece of the project is tied into the whole in terms of performance, responsibility and budgeting. The WBS is built from:

- the components from the PBS
- the infrastructure and assembly activities from the ABS
- the action plan for the project
- the basic phases in the project, for example design, purchasing, prefabricating, assembly, testing;
- and possibly the Cost Breakdown Structure (CBS) used for implementing the budget and for subcontracting the prefabrication and assembly.

The WBS is derived from many sources making it is possible to design many different structures. The aim of this first step of the planning process is to design the optimum structure, not too detailed to create administrative work, nor too abstract to preclude efficient project control.

At the top of the WBS is the objective for the project, the LHC. One can see from the lifecycle model that intermediate levels of the WBS are used to identify the sets of tasks related to the design phase (see Figure 1) at the start of the project and the test phase at the end. The lowest levels identify the set of tasks related to the materialisation phases.

Entries in the WBS are work packages. These are units of work to complete a specific process or job, owned by the planning co-ordinators. The 'leaves' of the WBS, *work units* (see Figure 2), have **(a)** one or more objectives **(b)** control points along with specific criteria[3] for evaluating performance, **(c)** known requirements of money, labour and other resources, **(d)** a named individual responsible for the outcome, **(e)** a relatively short life of less than two months. In terms of levels, a technical group owns the work unit and the planning co-ordinators can see its summary activity for consolidation into the co-ordination schedule.

At the beginning of the project the details of all the work packages, some of which will not start for ten years, are not completely and accurately known. However, because the work packages related to design phases are attached to intermediate levels of the WBS, a very accurate plan is feasible in the short term, and as the design proceeds the details of the rest of the project emerge. This implies that the WBS has to be actualised periodically, requiring a configuration management system to hold the current definition of the LHC and track the changes, and good communication between project teams to react to the changes.

Although the work units may be at the different levels of the WBS (this is also the case for the PBS, the ABS and the OBS), for labelling and communicating purposes the levels of the WBS must be standardised.

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[3] For example, number of drawings issued, cubic meters of concrete poured, meters of cable pulled, number of magnets tested. But not percent complete.

As described above, the WBS is a tree-like structure. There are two other ways of arranging the elements. When it is useful to consider function as well as elements in the machine a *WBS matrix*[2] can be used. The activity catalogue is a list of all elements in the WBS, arranged without any structure.

The WBS and the activity catalogue are prepared by the planning co-ordinators, verified by the technical groups and approved by the project management. It will be distributed to key project staff. Parts of the activity catalogue may be given to sub-contractors.

A detailed procedure for creating the WBS is shown in appendix A1.

3.3. Master schedule issue, approval, follow-up, actualisation

The master schedule is issued at the beginning of the project. It will have around 150 activities and events, and covers the whole project, from the design phase to commissioning. The master schedule is prepared by the planning co-ordinators, verified and approved by the project management. It is distributed to key project staff. It is used for assessing the progress of the project and communicating progress outside the project team.

The project action plan containing the key events of the project and their dates is required to implement this schedule. Activity duration is estimated from experience of building LEP and other accelerators. Preliminary co-ordination schedules may be used to consolidate the master schedule as they become available. The master schedule may be actualised at management request at most three times during the life of the project.

Progress schedules showing remaining durations will be issued monthly. Time progress is obtained by consolidating co-ordination schedules.

3.4. Co-ordination schedule issue, approval, follow-up, actualisation

The co-ordination schedules will be issued at the early stage of each of the major phases of the project: design, procurement & manufacturing, construction and testing. The WBS and activity catalogue are the basis of network construction and are required to implement these schedules. Each will have around 300 tasks. The co-ordination schedules are prepared by the planning co-ordinators, verified by technical groups and approved by the project management. They are distributed to the project key staff. With the formal approval of the planning co-ordinators, parts of them may be given to suppliers and sub-contractors.

Each schedule will fit within the master schedule with some time to spare. These risk limitation floats will be monitored by the planning co-ordinators. When available, detailed plans (level 3 schedules) may be used to consolidate the co-ordination schedules.

Schedules with progress marked on them showing remaining time are issued periodically: once or twice a month. Time progress is obtained from detailed schedules when they are available, that is for the next few months, by estimating remaining duration on the base of physical progress, remaining work, resource availability, or external constraints.

The project management or technical groups may request the actualisation of co-ordination schedules. If there is an impact on the master schedule, the project management’s must approve the change. These schedules should not be actualised more than twice a year.

3.5. Detailed schedule issue and follow-up

The detailed schedules are issued for the immediate future and cover a maximum of four months. The purpose of these schedules is: to show that the resources required to achieve tasks are available, and that the work to do is feasible in the time available — the planned duration of the co-ordination schedule’s corresponding *macro-task*.

These schedules can be issued by either the technical groups, the sub-contractors and supplier, or the planning co-ordinators. There are no specific limitation on the number of tasks. The detailed schedules can be actualised as often as required; at this level, monitoring the baseline is not required.

When issued by CERN, detailed schedules are prepared either by planning co-ordinators or technical groups, verified by technical groups and approved by planning co-ordinators. When issued by suppliers or sub-contractors, they are verified by planning co-ordinators and approved by technical groups.

3.6. Involving contractors in planning

Involving the sub-contractors and suppliers in the planning process is very important, when calling for tenders, when the contracts are awarded and later for the contract follow-up.

A schedule should be part of each bid. To simplify comparisons between bids, these schedules must be standardised. For this, the following steps have to be taken:

a) before the beginning of the procurement phase, prepare a procedure for the attention of the bidders explaining our expectations for both the bid and contract phases

b) when preparing the calls for tenders, prepare *skeletons* (one for each call for tender) that:

- list the activities which must appear as a minimum in their schedules
- show major interfaces, constraints and key events

c) compare the schedules presented by bidders, in addition to the usual technical, price and quality comparisons.

When preparing the skeletons, planners must be aware that a minimum of information is required: to enable us to distinguish between bids, the firms must have some freedom in preparing their schedule. The skeleton should have a realistic duration and links external events, but it for the bidders to add the details.

The selected contractors and suppliers must apply level 3 planning procedures: their detailed schedules must integrate key events from co-ordination schedules and they must report on a regular frequency.

3.7. Communication with and between technical groups

The interfaces between technical groups are monitored at the co-ordination level. The planning co-ordinators will assist finding a consensus solution to conflicts between groups. The three major causes of conflict are:

- interfaces between groups have not been identified or the task sequencing is incorrect — leading to postponement of linked tasks.
- a task belonging to a group is late (caused by, for example, underestimating the duration, insufficient resources, increasing the scope of the work, change orders requiring rework) — delaying the start of tasks in other groups
- a task is not feasible as planned (because of, for example, insurmountable technical difficulties or unexpected technical problems), which requires a review of, and changes to, the project network.

Planning co-ordinators have to minimise the consequences of such events. In some cases the risk limitation float is sufficient to solve the conflict. If not, *what-if analyses* are done on copies of the network to find the best solution. The decision making process starts by trying solutions without consequences on other work units, then without consequences on works units under sub-contractors or vendors responsibility, and then without too many consequences on the master schedule. The solution may require the actualisation of the co-ordination and master schedule.

3.8. Interfaces with financial controllers.

Cost controllers also have requirements, for example issuing commitment and payment schedules. Such information shall be taken into account into the procurement co-ordination schedule for committed costs, and in the construction co-ordination schedule for invoiced costs. Data are then exported to their system to produce reports on contributions and expenditure.

The financial controllers will need reports of contract progress. In will simplify the procedures if (as naturally happens in many projects) the planning co-ordinators become the central node for distributing information.

3.9. Progress reporting

The aim of a progress report is to depict the actual status and to compare it to that planned. Three measures of progress are useful: time progress, physical progress and worked time progress.

3.9.1. Time progress reporting

The aim is to record the time elapsed and the remaining duration for each task which has, or should have, begun. This applies to the master and co-ordination schedules. It is not suggested that the technical groups need not monitor progress. Indeed, the information for the co-ordination schedule must come from the groups. It is just that there is usually no need for others to see the details of a group's work.

Very often, tasks will not start when planned. One can hide this by arbitrarily altering the expected duration of following tasks, but it is better to find real solutions.

The remaining duration is determined by estimating the remaining physical work, past performance, resource availability, associated risks and the possibility of a re-definition of the scope of work.

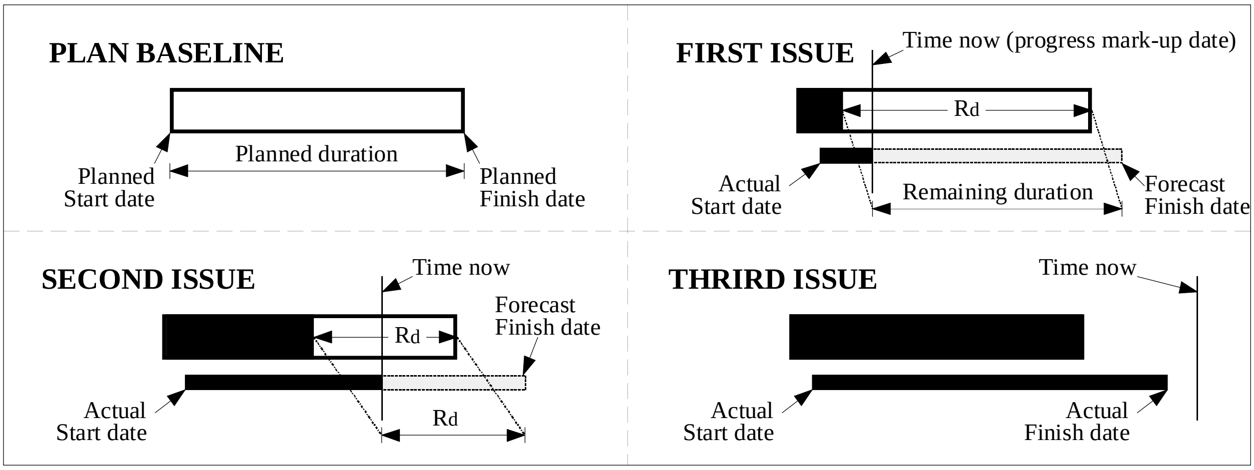

Figure 3 : Marking up progress

3.9.2. Physical and worked time progress monitoring and reporting[7]

The main objectives for measuring physical and worked time progress are: **(a)** to be able to **evaluate the performance** of the project, and **(b)** to be able to **see the overall progress** of the project. The performance of an activity is the physical progress of the task compared with the time worked, both usually expressed as person hours.

Progress may be estimated in different ways. Most methods are based on the same basic principle of allocating progress values to milestones — not the master schedule ones — defined in the project implementation process. Milestone are chosen because it is easy to see when they have bean achieved and there is no administrative overhead to recording this.

The assessment of physical progress between these milestones can be obtained in various ways:

- by manual estimation of the progress
- by assuming linear or gaussian progress between the milestones (continuous progress)
- by assuming no change in progress between the milestones (discrete progress).

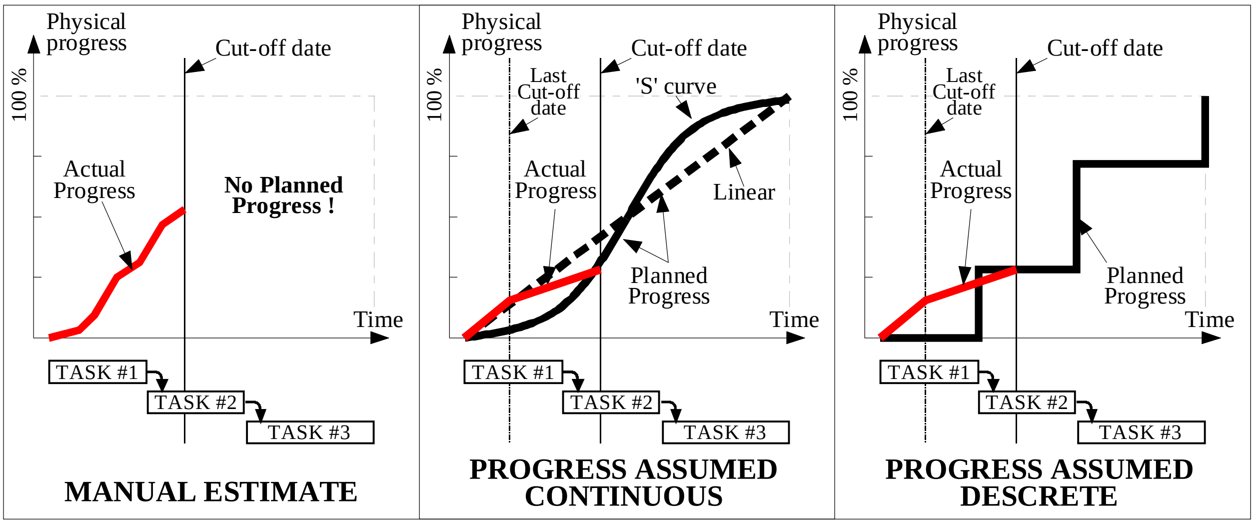

Figure 4 **: Physical progress assessment**

The planner can apply these methods at various levels in the planning hierarchy: to co-ordination schedule tasks, work units and most elementary tasks. The usefulness of each depends on the phase of the project. To choose between them will require a thorough analysis of their strengths and weaknesses in each phase and reflection on experience drawn from a variety of other large-scale projects at CERN, and, for example, those run by SGN at La Hague. The goal is to fulfil the objectives outlined above whilst minimising the work of progress calculation.

3.9.3. Monthly progress report

At a minimum the progress report shall cover the following points:

- the work which has been achieved in the period both qualitatively and quantitatively
- the problems which have been encountered in the period, the corrective actions taken (change orders) and the consequences foreseen for remaining work
- the actual status of the project verses the planned one, hence: master and co-ordination progress marked-up schedules, time schedule outlooks, physical progress summary and curves and worked time progress summary and histograms.

Every progress report will be prepared by the planning co-ordinators, verified by the technical groups and approved by the project management. It will be distributed to key project staff, and can also be used for communicating progress.

4. Planning tools

The nature of the planning tool one chooses depends on the project requirements and the software features necessary to support them, such as:

- **time analysis —** types of logical links, units of time, multiple calendars, fixed, resource or effort driven duration
- **resource analysis** — heterogeneous or homogeneous resources, multiple calendars, smoothing and levelling techniques
- **logical structures** — WBS, OBS, Resource Breakdown Structure (RBS)
- **cost analysis**
- **project tracking** — actual start and finish dates, planned vs. forecast dates and durations, physical progress monitoring
- **charting and reporting** — Gantt, PERT and Precedence charts, activity outlining, custom formatting, baseline vs. actual Gantt charts

There is a difference in the requirements between design, procurement and construction at the beginning of the project and installation and testing toward the end. Experience gained during LEP suggests that when there are few links between work packages — when the WBS matches the OBS — they can be effectively decoupled. This is what is foreseen for the LHC.

During installation the different groups must work closely together. So for the installation phase there is a much tighter coupling between work packages. Work is also constrained by the confines of the tunnel and there is a need to view tasks by their position in the tunnel. The level of co-ordination required demands the integration of the detailed activities into one network. The need to see the position of activities requires access to standard codes stored in Oracle.

The software must allow sufficient numbers of, for example, tasks, calendars, breakdown structure levels and resources, and process them in reasonable time.

Most planning packages run on one of a few well-known platforms: 68% on PC/MS-Windows, 22% on UNIX workstations and 12% on Mac[8]. Most of them run on only one — just seven of the 67 planning tools listed in this article[8] are available on all three of these platforms. Not all of these use a database to store data.

Other organisations are rejecting the single network approach, together with complex planning tools, in favour decentralised detailed planning and central co-ordination using simple tools. Some examples are:

- Hibernia: a six year, 7000 M US$ Mega Offshore Platform in Canada
- UP2-800 at La Hague: an eight year, 10000 M FRF Nuclear Fuel Reprocessing Plant in France
- CBS: a ten year, 300 M ZAR telecommunication project in South Africa
- the Siemens world-wide planning division, responsible for all Siemens project planning.

4.1. Present situation

Software Tools

There was a project to find a replacement for the LEP planning package, POL, between 1990 and 1994. The criteria were that the package should replace the functionality of POL, be more user friendly and be a commercial product. In September 1994 CERN bought a planning package that met these requirements, called P/X.

Powerful enough to integrate all the time and resource planning for the LHC, P/X appeared to be the most user-friendly software that met our requirements. Despite this, experience at CERN and at other organisations[9] has shown that the software is sufficiently difficult to use to put off many potential users.

Many of the advanced features, which differentiate P/X from cheaper competitors, are particularly difficult to use. However, once mastered, it is extremely useful to a central planning office if a monolithic, single level network is foreseen.

Many people at CERN have experience of using Microsoft Project and have found it easy to use. Typically, people use it for small projects, or the outlines of larger ones; only time has been considered and not resources. Although available at CERN, Microsoft project was not considered as a POL replacement, because it did not have the necessary features. In particular, there was no link to the Oracle database system. However, recent versions of Microsoft Project now have much more functionality.

Hardware

There are three types of computer commonly used at CERN: PC, Macintosh and UNIX workstation.

New versions often appear first on the PC and sometimes not at all on the other platforms. The next version of MS-Project, version '95, should appear by November for the PC and will allow direct access to Oracle databases, whilst Project version *four* has just arrived for the Mac. P/X currently runs on PCs and UNIX workstations, whilst MS-Project runs on PCs and Macs. PSDI, the vendors of P/X, will not continue supporting UNIX because of lack of sales, the need to concentrate development resources and the ease of use that can be achieved by developing for only one system, the PC running Windows.

Development tools that allow the software developer to be very productive and to integrate data from several applications are available for the PC and supported by the CN division.

4.2. Choosing the LHC planning tools

LEP experience showed that planners mostly worked with time scheduling. They used, typically, neither cost control nor resource levelling. The ratio of benefits to costs of using a simple tool is much higher than for using a complex tool. And if there is no benefit the planner may wish to use a simple tool.

There are several solutions possible:

Solution no. 1: everyone uses P/X including collaborating institutions and contractors.

☺
- availability of P/X features to all planners involved with LHC project
- all planners share the same database (as for LEP with the POL software)

☹
- price of the software: the licenses and maintenance payments are expensive
- training requirements for group's planners and time required to become merely proficient
- P/X does not run under MacOS, what means extra PCs are required
- P/X is a powerful tool for the full time planner, it is too complicated for others to use effectively
- it will be difficult to persuade sub-contractors and external organisations to use it.

Solution no. 2: all at CERN use P/X, but MS Project is standard data format for external organisations; the central planning database is in P/X format for consolidating information.

☺
- availability of P/X features to all CERN's planners
- at CERN, all planners share the same database
- MS-Project is the most widely available planning software, many sub-contractors might have it already

☹
- price of the software: the licenses are quite expensive
- training requirements for group's planners and time required to become merely proficient
- P/X does not run under MacOS, what means extra PCs are required
- data integration from MS-Project format files to the central planning database necessary.

Solution no. 3: planning co-ordinators use P/X, others can use either P/X or MS-Project, once again with a central Planning Database

☺
- planners share a central planning database via MS-Project file data integration
- P/X still the tool to produce global views
- MS-Project is very affordable at $695, and it can run either on PCs and Macs
- Ease of use of MS-Project implies reduced training requirements
- MS-Project is the most widely available planning software, many sub-contractors might have it already

☹
- data integration from MS-Project format files to the central planning database necessary and will not be as seamless as if P/X only is used
- coherency of the data: the difficulty of keeping the data used for MS-Project in step with that in the central database
- to run perfectly, the planning process (described by planning procedures) must be followed precisely, otherwise the project planning control system will be totally inefficient

Solution no. 4: everyone uses MS-Project including collaborating institutions and contractors.

☺
- MS-Project is very affordable: $ 695 and can run either on PCs and Macs
- Ease of use of MS-Project with the consequence of reduced training requirements
- MS-Project is the most widely available planning software, many sub-contractors have it already

☹
- the central planning database cannot (yet) be Oracle, although links to Oracle are possible
- sharing a Project file over a local network is slow and requires well-configured computers (Pentium 66 or PowerPC with 64 Mb RAM as a minimum)
- to run perfectly, the planning process (described by planning procedures) must be followed precisely, otherwise the project planning control system will be totally inefficient

Solution no. 5: planning for LHC is contracted out.

☺
- staff at CERN may be reduced

☹
- an expensive option that would be paid for from the material budget, without any of the costs hidden in the personnel budget
- success in previous projects relied on the free flow of information between technical groups, planners and managers that would be inhibited if the planning group were based outside CERN.
- loss of ownership of plans and of control over the project.

4.3. Conclusions

The use of sophisticated planning software (database orientated, offering techniques like *chemin-de-fer*) during the installation phase is required to achieve the planning process goals. For the design and procurement phases, such software is not necessary.

A short look at the evolution of planning software and operating systems over the last few years leads to the following observations:

- the duration between new versions is becoming shorter, 2½ years between MS-Project versions 2.0 and 3.0, and 1½ years between versions 4.0 and '95
- the longevity of major products is dependent to the number of customers, we can believe that with thousands of customers, affordable software such as MS-Project, Scitor Corp.'s PS6 or Computer Associates' SuperProject will still on the market and supported within 5 or 10 years. P/X claimed 70 customers in their bid.

- the tendency for affordable software to have as much functionality as sophisticated packages: according to Microsoft, Project’95 will fully support Oracle; we can imagine that future versions (or add-on products) will support the *chemin-de-fer* method and efficient progress monitoring.

There is a large gain, for little effort, for planners in the technical groups, external collaborators and contractors, in using a simple tool simply, and little extra gain and much effort in using a complex tool. It is in the interests of everyone to involve as many project members as possible in the planning process. This will be easier if the tool chosen to help them is not itself a barrier to be overcome.

The specification that lead to the purchase of P/X was based on the working practises that grew up for LEP and embodied in POL. The LHC project is different in three significant ways. The technology required is not yet completely known so there is a research and development component, the funding is considerable tighter, and the fair return policy has a great impact on the organisation of contracted-out work. In the time since POL was written to plan LEP, planning practises and user expectations of software and computer hardware have all changed.

The definition of a planning process for LHC allows us to reconsider the requirements of the tools needed to support that process. Not surprisingly, the tool chosen in the light of the new project, new planning practises, new software expectations and new hardware, is different from that chosen as a replacement for POL.

For the first part of the project (that is, until the construction and installation begins) it is possible to decouple each work package from the next. Each technical group will make their own plans. Now the planning process provides the co-ordination between groups rather than the planning tool. Without the need for a single network containing many thousands of tasks, the constraints on the choice of tool become less restrictive. Now CERN can choose a tool that is easy to use, cheap to buy, without maintenance charges and with very little training cost. This tool is Microsoft Project.

During the installation phase the requirements are somewhat different: there are more links between the work of the technical groups and a greater need to use codes held in Oracle databases. Thus, five years into the project the choice of tool will need to be reconsidered — we may need something more powerful than Microsoft Project. But for the majority of the project (at least) we can benefit from using Microsoft Project.

MS-Project runs on both PC and Mac computers. Version 4.0 is available for both and has similar facilities. To support both PC and Macintosh will mean maintaining two sets of tools. This will take resources away from implementing the requirements of the project management, financial controllers, planning co-ordinators and technical planners.

Microsoft Project is the preferred software, and the **PC** is the preferred hardware, for planning LHC.

5. Defining the planning process

This paper describes a philosophy; it is not detailed enough to be use as a procedure. The **Planning Process Quality Assurance Manual** (QAM) to be published will describe, in detail, these areas:

- WBS issuing and actualising
- Master Schedule issuing and actualising
- Co-ordination Schedule issuing and actualising
- Detailed Schedule issuing and updating
- Note of Associated Conditions issuing
- Document & Schedule numbering/registering and List of applicable Schedules
- Time Progress monitoring and Progress Mark-up Schedule issuing
- Physical Progress monitoring
- Progress Reporting

In particular, the QAM will specify the use and limits of use of the planning software through each stage of the project. After testing the software, it might prove necessary to slightly change the planning system to match the facilities available.

5.1. Pilot projects

There is the opportunity of testing the management set up and its associated tools during the LHC first phase (until Mid 1998) using the in-house prototype assembly and the related sub-components supplies. Itshould not be missed.

Detailed plans for Civil Engineering works are already underway and may be used to help define and test the planning process.

5.2. Action Plan

Before people may start work, the planning process and planning tools must be ready, and of course, the people who will make the plans appointed and trained. The master plan will be ready by the end of September, the PBS and ABS ready by the end of October, the WBS ready by the end of November.

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Appendix 1

WBS construction

The following procedure describes in detail how to construct the WBS:

I. define the level of detail for each axis of the WBS matrix and implement a preliminary WBS with project management and cost estimators

II. complete and validate the preliminary WBS (with technical groups)

III. issue a preliminary list of work units, and for each of them:

  A. estimate cost (with cost estimators), labour and resources (with technical groups)

  B. make a preliminary estimate of its duration and specify which master schedule task to which it belongs

  C. list the required input, for example materials and information, specify the deliverables — intermediate and end results

  D. identify who is responsible for the work unit and construct a *linear responsibility chart* that shows these responsibilities.

  E. list any suppliers or sub-contractors who will be involved

IV. collect this information to make the LHC project activity catalogue — a sample collection form has been appended to this paper

V. review the activity catalogue as follows (with technical groups):

  A. check interdependencies between work units, and subdivide each into tasks which reflect these interdependencies

  B. split up long lead work units to remain relatively short in time span

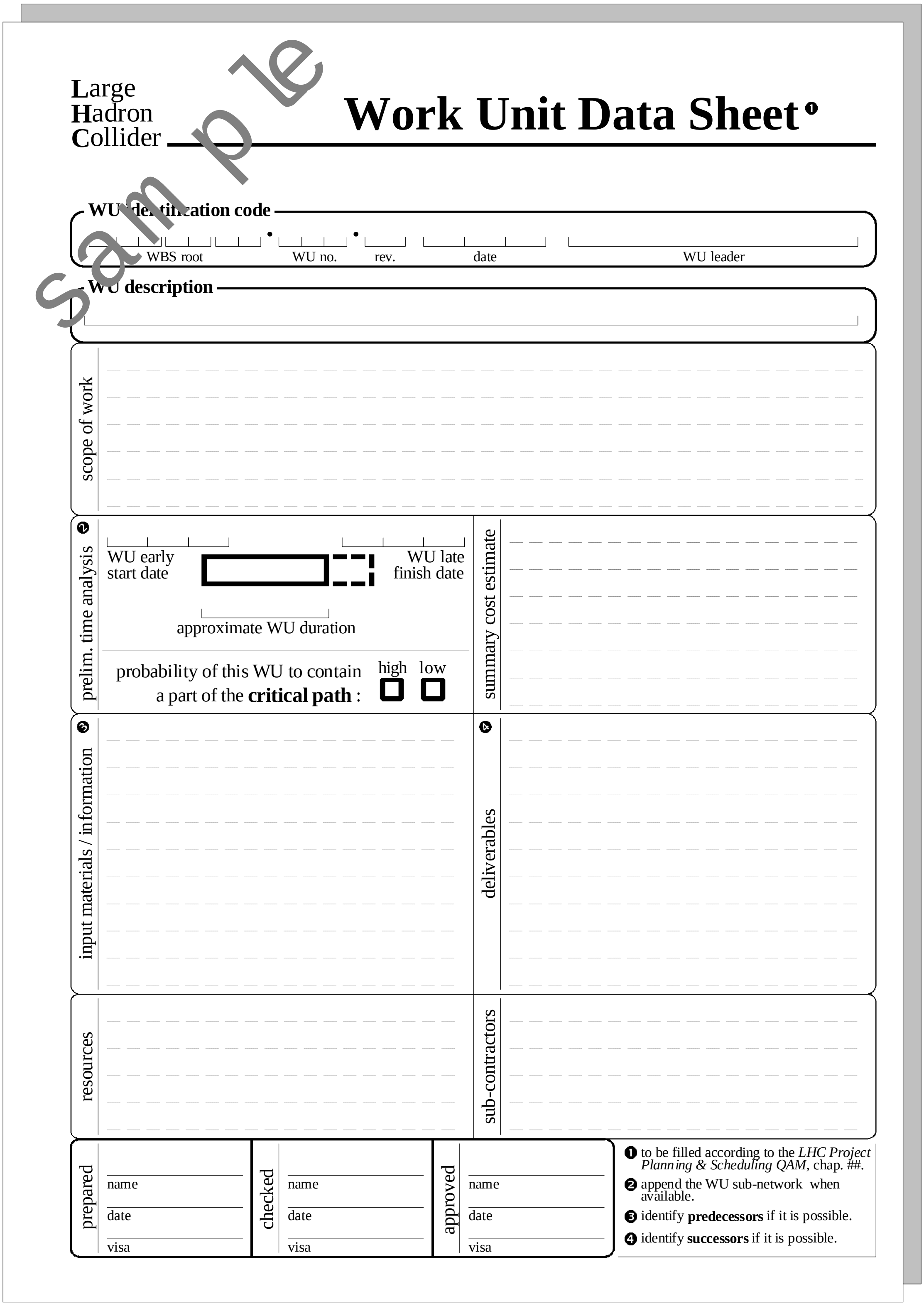
  C. estimate the minimum duration (or number of hours of labour) and resources required to accomplish each of task; ensure that precedence relationships are specified for all immediate predecessor activities and events

  D. if necessary, review the cost and resources needed

VI. review the WBS once again (with technical groups) when the co-ordination schedules are available.

Appendix 2

Sample « **Work Unit Data Sheet** »



Large
Hadron
Collider

Work Unit Data Sheet ❶

WU identification code

WBS root . WU no. . rev. date WU leader

WU description

scope of work

❷ prelim. time analysis

WU early start date

WU late finish date

approximate WU duration

probability of this WU to contain a part of the **critical path** : high ☐ low ☐

summary cost estimate

❸ input materials / information

❹ deliverables

resources

sub-contractors

prepared	name date visa	checked	name date visa	approved	name date visa		

❶ to be filled according to the *LHC Project Planning & Scheduling QAM*, chap. ##.

❷ append the WU sub-network when available.

❸ identify **predecessors** if it is possible.

❹ identify **successors** if it is possible.