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WHAT TO BE IMPLEMENTED AT THE EARLY STAGE OF A LARGE-SCALE PROJECT

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Abstract

This paper addresses the importance of the actions to be taken before the project planning phases begin. The approach taken stems from the production planning paradigm, with emphasis on the product, rather than on the process. It is argued that a complete part list or product breakdown structure (PBS) is the absolute prerequisite for the design of a successful work breakdown structure (WBS) for a project. This process requires the definition of the design and configuration disciplines during the engineering phase. These critical issues of concurrent engineering and product development are also emphasized in the paper. The WBS is, in turn, needed to establish a suitable organizational breakdown structure (OBS or organigram) for the project. Finally, the assembly sequence and the related assembly breakdown structure (ABS) of the end product is required before commencing the project planning phase, which provides the schedules, resource allocation, progress control, and the like for the project management. Detailed definition of the product enables the definition of the work packages within the WBS, which combined with the installation information provide the means to structure the layout for the project organization. The result of the entire process, that begins with the product definition phase and ends with the completion of the planning phase, is called the project management plan. The procedure described in the paper will be used to design the project management plan for the Large Hadron Collider (LHC), a ten-year "ordeal" commencing at the beginning of the 1995, at CERN.

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1. Preamble

The traditional approach to organizing any production effort has been called the functional approach. This would include the structuring of processes according to their function, i.e. operations with the same function are grouped together. Yet, this approach has been proved to be in many cases obsolete [1] and more recent work focuses on product-oriented organizations. In production management, for instance, this means that the layout and organization of a company are designed in such a way that the material-flow system is as simple as possible, which results in fast throughput times and minimum work in progress. These in turn correlate with better quality and improved delivery performance. For a large-scale project the analogy with production management provides us with the following statement: **the project organization should be formulated to correspond to the work-breakdown structure, which is dictated by the product structure**.

Traditional project planning methods focus on various network techniques such as the critical-path method (CPM) and the Program Evaluation and Review Technique (PERT). The study of modeling and of creating new algorithms to tackle a large variety of resource allocation and scheduling problems through network methodologies has dominated the academic approach to project and production management and control. However, these methods respond to only one specific problem in the whole process of managing a project. The work-breakdown structure is the backbone of the proper planning, execution and control of a project [2]. This issue is partially neglected in the literature. Various project planning manuals do not even treat the subject of how the WBS is actually constructed and what other issues should be looked at, this, despite the fact that large high tech projects are using this technique. In this paper these issues are discussed both from the product design and from the project management point of view.

Previous research has shown [3] that most one-of-a-kind projects have substantial delivery time and cost reduction potential. It has also been stated that shortened delivery times reduce process quality problems, which contribute to successful project outcomes and financial savings. Many industrial companies producing one-of-a-kind products have realized that the origin of changes in the product specifications during the assembly phases do not stem from the customer but from the in-house engineering procedures. All this implies that a well prepared pre-assembly phase significantly reduces configuration changes. These and other empirical facts from industrial studies in one-of-a-kind production and logistics motivates us to place emphasis on the procedures before the planning phase.

The Large Hadron Collider (LHC) project, accepted by the CERN* Council in December 1994, starts a new era in high energy physics. The new collider will provide the means to look even further into the structure of matter. As a project management task the LHC sets a new challenge for CERN. Yet CERN is not starting from scratch in large project management: the Large Electron-Positron Collider (LEP) project has already taught us many practical things which are relevant to the construction of the LHC [4]. Thus, by exploiting this experience with the use of modern methods, the task will be accomplished.

This paper is structured in the following way. First, the product breakdown structure (PBS) and how it is constructed, managed and controlled, is treated. The PBS is the same as a bill-of-material or part-list. As the PBS describes only the product itself, an assembly breakdown structure (ABS) is needed to describe the assembly sequence of the final system. Whether the product is a satellite launcher like Ariane 5 or a particle accelerator, the ABS comprises the information on logistic, material availability and other constraints of the actual assembly location, which affect the final construction sequence of the product. Next the focus is on procedures needed to formulate the WBS after the PBS and ABS are available.

* CERN, the European Laboratory for Particle Physics, has its headquarters in Geneva. At present, its Member States are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. Israel, the Russian Federation, Turkey, Yugoslavia (status suspended after the UN embargo, June 1992), the European Commission and Unesco have observer status.

Then the organizational-breakdown structure (OBS) is defined from the WBS. The actual project planning phase may commence after the WBS is defined, yet it cannot be completed until the OBS is available. Figure 1 shows the sequence of activities needed to establish the LHC management plan (for an overview of the LHC see [5]). The paper ends with risk assessment, integration of the planning system with logistic and purchasing systems and reflections on the experience in one-of-a-kind industries.

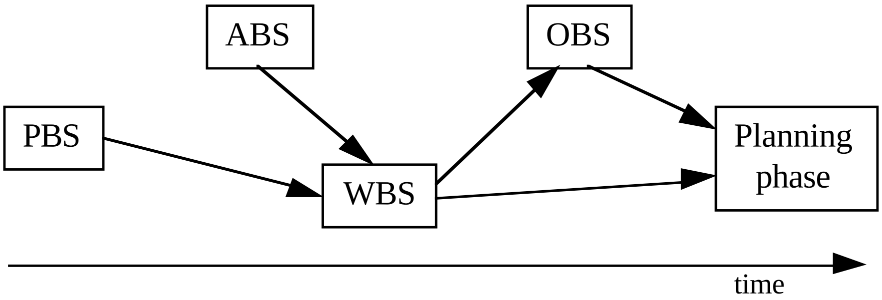

Figure 1. Main procedures to establish the project management plan.

2. Product-breakdown structure (PBS)

Most products are made of components, which are composed of parts. Each part may be divided into sub-parts and so on until the elementary parts are reached. Each subdivision also includes assembly information: how the lower level parts are processed to reach the upper level component. An elementary part, such as a screw, shares no other parts, yet it possesses several attributes concerning its size, thread, head and so on. If the elementary part is to be manufactured then the attributes also include instructions on how it is to be processed and from which raw materials it must be made. The PBS comprises all this product configuration information in a tree structure, in which the leaves are the elementary parts. Thus, to summarize, the PBS comprises the following information:

- product tree structure describing the complete configuration of the product;
- instructions on manufacturing, machining, quality control etc. for each level and branch of the product structure;
- technical description of the elementary parts, i.e. the leaves, of the product structure.

In most companies with discrete production facilities the PBS is used as the fundamental data structure to control material, production and information flows. Various versions of material requirement planning systems (MRP) and material resources planning systems (MRPII) are being used in industry [6]. These systems allocate the production resources according to due dates, provide assembly information for production and control the inventories and purchase operations. All this is based on bill-of-materials, a notion used by bulk industries, which is analogous to the PBS of the large scale project business. To form a feasible basis for the project planning phase the PBS has to exist, even though all the information concerning parts and their attributes may not be available. Thus, there may be some variations in the product information, which do not affect the overall PBS. Major changes in the PBS require one to restart the preplanning process, described in figure 1, right from the beginning. **The configuration to the last detail of the product is to be closed before the final plans concerning the project are fixed**

The process to build the PBS from all the bits of engineering knowledge scattered around the organization requires centralized management procedures. The PBS should be placed in a centralized database, which manages the technical information according to defined principles. Guidelines for coordinating technical information between various component planning projects exist [7]. The idea is to label each part or sub-project with a technical planning status indicator: *frozen* if the components may not be modified any more or *private* when the part may copied to another project or modified within the same project. In addition to this there are several modification rules to control changing the component/part/project status, copying/sharing component configuration between projects, authorization rights, and links between projects. This framework provides practical means for the design and control of the project, which partially assures that the assembly phase for the project will be successful.

One of the main components of the LHC system is the dipole cryomagnet consisting of a so called cold mass (the magnet proper, figure 2) housed in its cryostat. The overall length of this cryomagnet is about 16.5 meters, with a diameter of 1.1 meters and a weight of approximately 30 tons. As an example the cold mass is made of assemblies of some 200 different sub-components, some being unique and others in quantities of more than 5000.

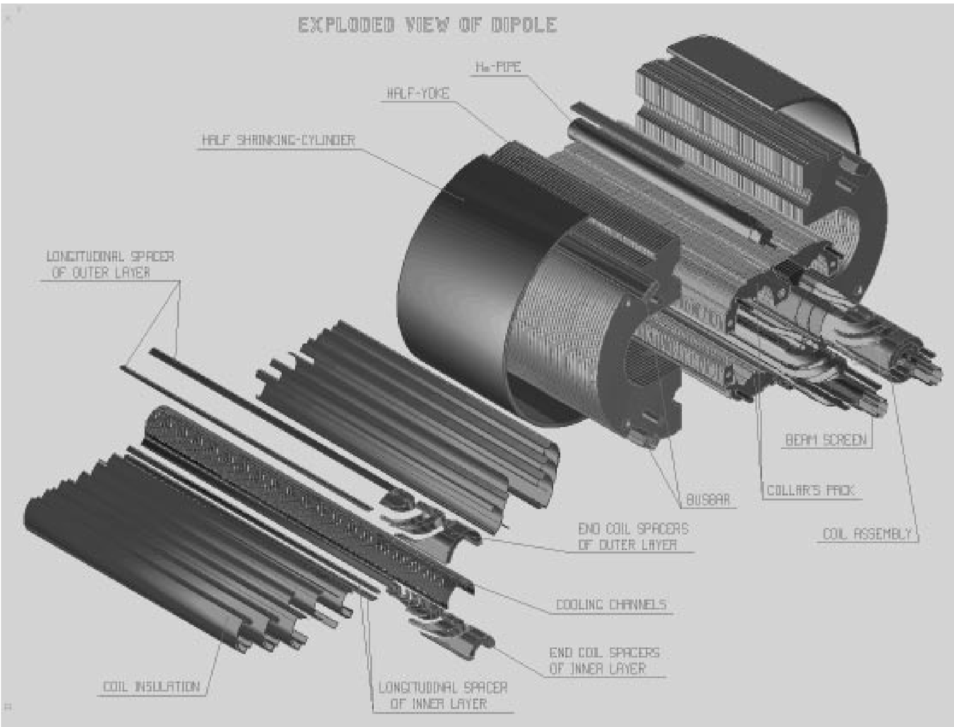

Figure 2. An exploded view of a dipole magnet cold mass.

Although the final configuration of the dipole magnet is not yet fixed, the following tentative PBS, without the relevant manufacturing and assembly information, can be made (figure 3):

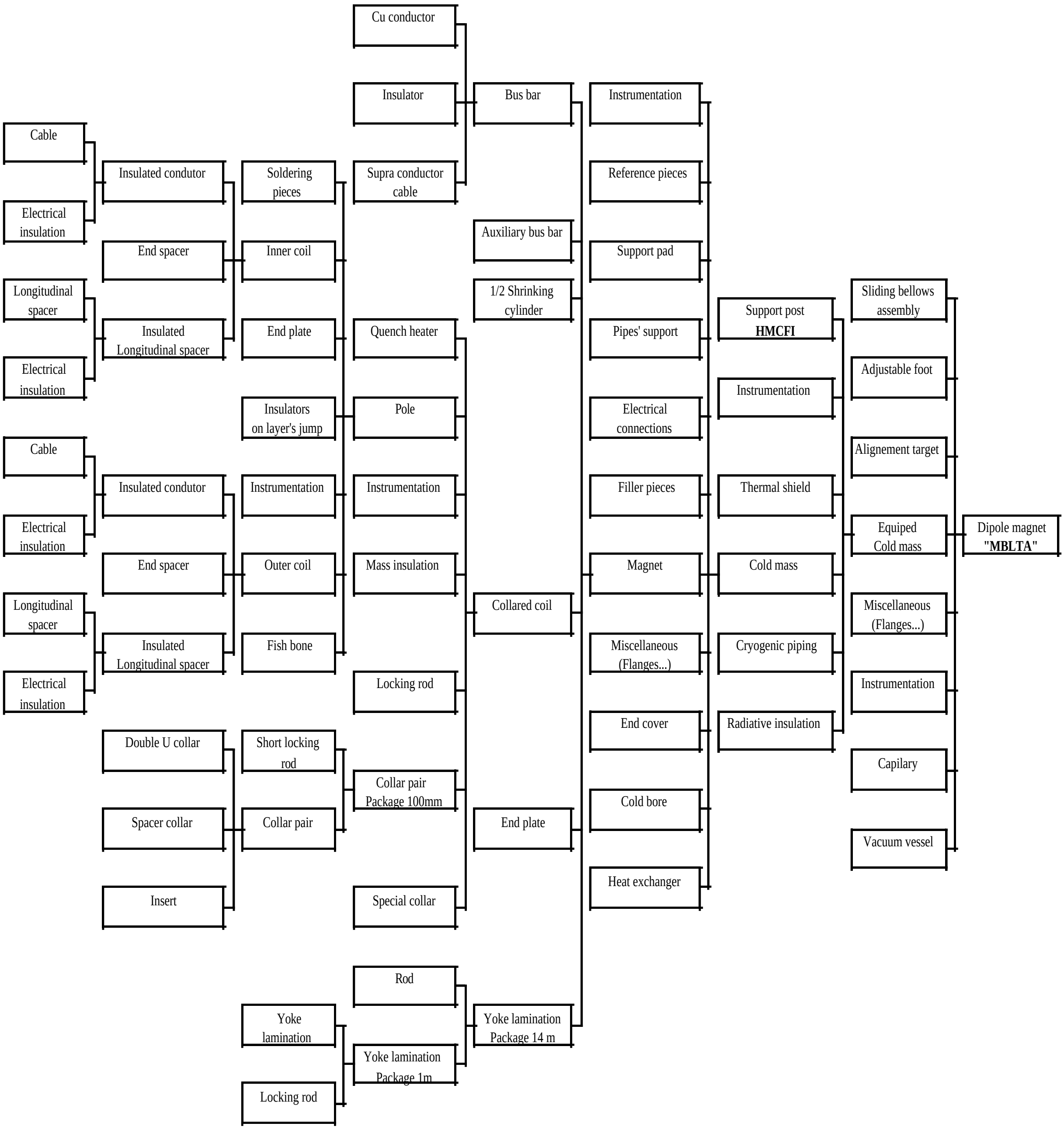

Figure 3. A draft PBS for the dipole cryomagnets.

Establishing the PBS is the first major task for the LHC-project management. This calls for the following actions:

- *Technical identification of each component/part of the end product.* A common agreement on how to identify, name and document each component and part of the LHC. This is extremely important for the building of the centralized database, which requires the labeling of each component with a unique name.
- *Establishing the database for the management of the product information.* The information will be stored in several separate databases, however, it must be viewed as one entity to ensure the coherence of the sub-projects.

- *Include in the PBS the manufacturing, assembly and quality control information for each component*. Each branch of the PBS includes parts which are manufactured and later assembled.
- *Organize and execute the collection of product information*. The knowledge of the LHC as a product is held across several engineering groups, this information is to be accumulated in database, together with the relevant attributes and links to the technical systems (e.g. the technical drawings libraries).
- *Further develop, validate and implement the rules of design and control*. As the design is under continuous development and subject to change, design rules should be used to minimize risk during the later steps of the project.
- *Analyze and verify the PBS*. Once the first version of the PBS is available, the structure is tested and the connections between various parts assessed. Defects are corrected and the design and control procedures manage changes to product specifications.

3. Assembly breakdown structure(ABS)

Most large scale projects are the culmination of several major sub-projects, each providing parts to be assembled together into one functional entity. Whether the project is an ocean cruiser or a nuclear power station, the assembly phase and assembly location constrain the final assembly sequence. The assembly breakdown structure (ABS) complements the PBS to provide the WBS and planning phase with the relevant constraints. To summarize, the ABS contains the following information:

- A description of the time related sequence of activities needed to be taken to complete the project.
- Part and activity related information that alter the original assembly sequence given by the PBS.
- Other information related to the activities and the site, which influence the WBS development.

The ABS of a large-scale project may be included in the PBS or taken into account during the WBS formation. In most cases, however, the PBS and the ABS differ from each other significantly. The ABS may be embedded into the PBS or it may be a separate structure treated in the same way as the PBS. With the LHC the ABS includes all the information concerning the final system assembly. While PBS comprises the manufacturing and assembly information of individual components, the ABS displays the assembly sequence and the related installation information of the components forming the functional LHC system.

The LHC system will be installed in the existing 27 km tunnel already accommodating the Large Electron-Positron Collider (LEP) (see figure 4). Thus, the existing infrastructure provides the initial constraints for the ABS.

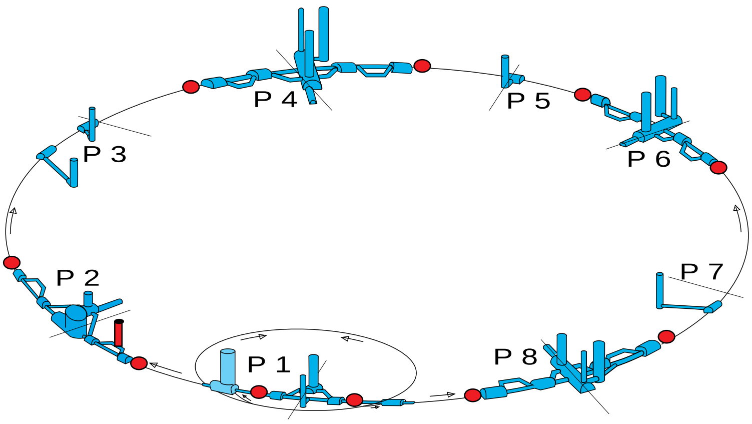

Figure 4. The LEP underground tunnel and the related main facilities, i.e. shafts and experimental areas.

Additional civil engineering necessary for the LHC system assembly will be described in the ABS. A preliminary ABS, without installation and prioritization information, may be made (figure 5).

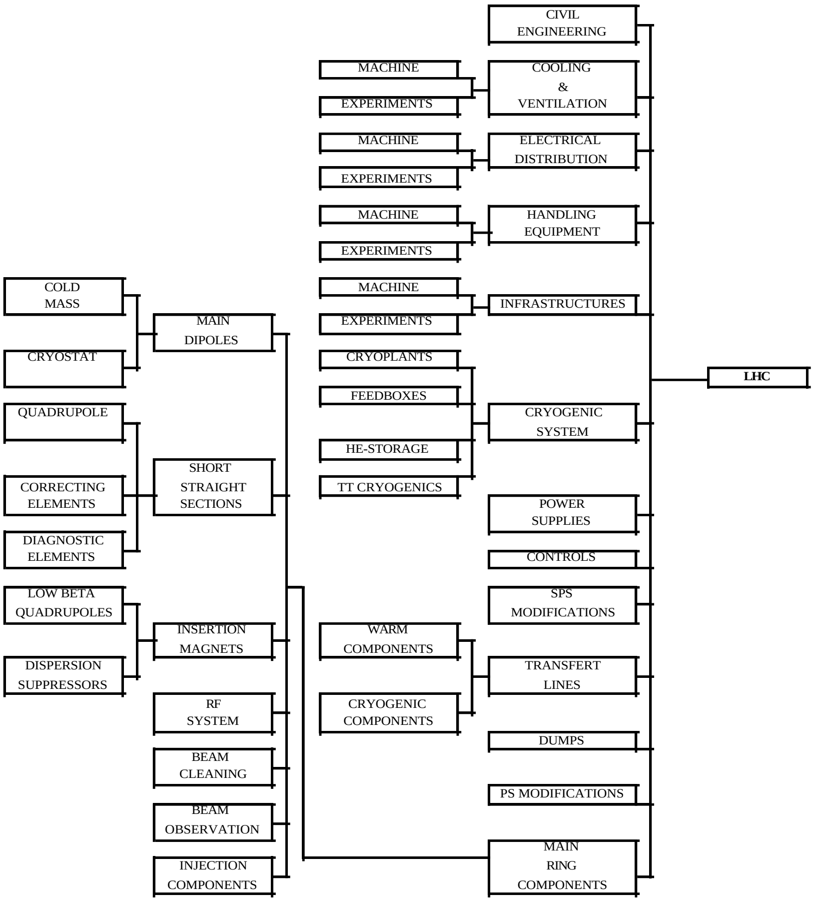

Figure 5. A draft ABS for the LHC.

Bachy, G., Hameri, A.-P., “What to be implemented at the early stage of a large-scale project”, CERN and Helsinki University of Technology, February, 1995.

It is important to include in the LHC project management plan relevant information concerning site constraints. The following actions are needed:

- *Analysis of the various ways to utilize the current layout of the site*. There are several alternative sequencing possibilities to assemble the underground installation. All of these should be studied and the most convenient one should form the basis of the ABS.
- *To complement the PBS with information about the installation tasks*. This includes the identification of problems related to the surface and underground movements of the sophisticated instruments with significant physical dimensions. Most probably this will require additional planning procedures.
- *To integrate the above to form the ABS*. This structure is needed to build a reliable WBS for the project, which is in turn crucial for the overall success when measured in terms of time, cost and quality.

4. Work-breakdown structure (WBS)

A lot of research effort has been used on activity network analysis and other methodological issues concerning resource allocation and scheduling. This research partially ignores the fact that **it is almost impossible to generate a proper activity network without establishing the WBS of the project** [2]. The PERT Coordinating Group [8] defines a WBS as a family-tree subdivision of a program that begins with the end objectives, and subdivides these objectives into successive smaller subdivisions. This means that a project is decomposed into objectives, which are actually a mixture of activity and component information described by the PBS and ABS. These structures are cross-referenced to form the WBS, which provides the framework for defining the work to be accomplished and for constructing the network plan. In addition to this it sets the infrastructure for cost and schedule control.

The top level of the WBS refers to the project or to the one-of-a-kind product to be accomplished. The second level may refer to main component classes, functions or in some cases to geographical locations. The third level is different from the second, in such a way that if main components form the second level the functions may occupy the third level or the other way round. How the levels are actually defined directly influences the organizational structure of the project. The ‘leaves’ of the WBS are called *work packages*, each of which is a unit of work needed to complete a specific job or process, such as a design, report, document, artifact or service. At the very detailed level the work packages may be further divided into activities, which, in turn, consist of elementary tasks. Thus, there is a certain degree of freedom to construct the WBS; whether functions or main components form the second level, and how detailed and deep the breakdown should be. The last point touches upon where the line of responsibility and individual planning independence is drawn. **An over detailed breakdown leads to extra administrative work, and one too loose often leads to poor control of progress and costs. These issues are of utmost importance and form the policy guidelines for the whole duration of the project**.

For the purpose of the LHC, the WBS will comprise both the main project management functions and the main components of the system. This is presented in a matrix form, where each cell forms a work package with its own objectives. Schematically the matrix interconnects the relations between main management functions and main components. This division is further developed towards the part level of the main components (see figure 6).

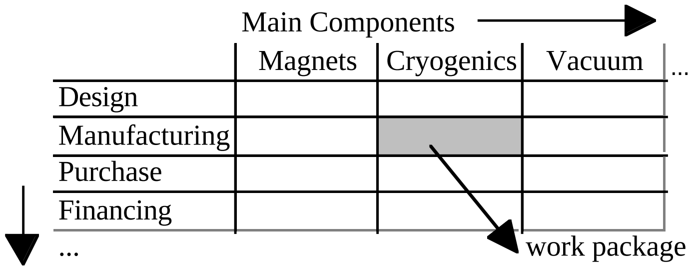

Figure 6. By combining in a matrix the main management functions with the main components of the system the work packages are defined for the WBS.

A work package is a separate entity which includes several activities forming the activity network. Activities may have connections to other activities outside the work package. The activity network of one work package describes the workflow, actions, and outcomes of the package. The lead time for a work package is calculated from estimated duration of the activities, which together with the resource requirements form the input to the planning and allocation phases. As the project will last several years, even a decade, **the WBS is not a rigid, but subject to changes, which requires flexible project management**. In practice this calls for procedures to manage project configuration changes, which enables expeditious changes to various project management structures and quick replanning and reallocation of project resources and activities.

To summarize, the main tasks in creating the WBS for the LHC-project are:

- *To define the WBS to the required level of detail*. To construct the WBS for the LHC, two breakdowns are needed: the first based on the functions: design, manufacturing, purchase, personnel, financing etc., and second breakdown based on main components: magnets, short-straight sections, vacuum, cryogenics etc. These breakdown definitions are merged into the previously mentioned matrix presentation, to form the work packages. In the literature, the experience from large-scale projects suggest that four to six levels seem to be adequate to build up the WBS. How wide the structure is depends on the project, yet the width and depth are correlated.
- *To set the main objectives for each work package*. Whatever the breakdown of the project structure, **each work package should have clear and simply stated objectives**. Objectives are to be assigned to every level of the structure.
- *To provide the necessary tools to manage and control the WBS*. Project management tools and the WBS are integrated to build up a workbench to maintain the project configuration and the links between external systems, such as the financial and personnel systems. The project documentation should be made simple and accessible.
- *To define the activities and possibly also the tasks needed to complete each work package*. Each work package requires activity specification in order to achieve the imposed objectives. Activities may be further divided into tasks if needed. In practice these tasks may relate to safety and other instructional issues.
- *To assign the responsible individuals or work groups to each work package*. This overlaps with the definition of the project's organizational structure, but **it is important to commit the key persons to the work as early as possible**. Their responsibilities include not only the achievement of the objectives but also documentation and financial obligations.

- *To establish project configuration management*. The project management plan will certainly face several changes and adjustments during the project. This calls for special project management skills to restructure and reorganize the project configuration without any major disturbances in operational project work. In addition to this, **the project management must provide all collaborators with an easily accessible source of information containing the current understanding of the system configuration** (key parameters, measures and standards of the system, status of the various component configurations, quality requirements, responsible people, etc.).
- *To provide financial estimates concerning work load and other related project costs.* The WBS is used for the first budget plan, which can be further studied and adjusted. Also preliminary mapping concerning the project risks is to be carried out.

5. Organization breakdown structure (OBS)

The skills of the available people should partially determine what kind of breakdown is made at the top-levels of the WBS. Usually the existing organizational infrastructure dictates the upper level breakdown of the WBS. Thus, the WBS should not significantly contradict the existing OBS; nor should the OBS dictate the WBS. In practice the people responsible for each work package form the basic organizational structure, which, in turn, is usually based on natural resource clusters that have evolved in the organization. **Radical changes in the existing organization and unnecessary project start-ups from scratch will jeopardize the natural and already functional communication and decision channels, which should instead be exploited by the project**.

The first step for a new project is usually to nominate a project team to work on the preparatory phases: producing the WBS, the OBS and the first detailed plan. This team is usually responsible for the whole project. [9] provides advice on how the overall atmosphere should be built up. During the building of the project management plan the active involvement of the participants is necessary, which is more or less a *democratic* process. Once the implementation phase commences the management should act increasingly in *authoritarian* manner to ensure that the plan is executed in a goal-directed manner. This requires leadership skills from the project management team in addition to technical and administrative competence.

To summarize, the OBS provides a detailed framework for people, their organizational relationships and the WBS. In addition, it includes authority and reporting obligations. To construct the OBS for the LHC-project the following tasks are necessary:

- *Identify the natural parts of the existing organization to be used in the project*. To exploit the synergy of the WBS and the existing infrastructure, including the various pilot projects and task forces already studying technical solutions for the LHC.
- *Inform people of the common goals and management principles*. To disseminate the main objectives and the project progress assessment criteria. All parts of the organization must share a similar understanding of the overall managerial objectives of the project. **As the project is complicated the management principles should be simple and clear to everyone**.
- *Generate a matrix organigram with personnel, component and functional dimensions*. To provide the management with the required flexibility, a matrix organization will be developed using the same presentation as for the work package derivation (figure 6). The top level of the LHC-organization may follow the traditional line structure, yet the rest of the organization requires easy movement of resources without organizational hindrance.

- *Generation of communication procedures and documentation protocols*. As the organization is a collection of independent units, the information practices and documentation conventions should be predefined and standard throughout the project.
- *Evaluation of future organizational needs*. In long term projects the organization is subject to changes. This requires far sighted reasoning from the project configuration team to estimate the future resource needs. With certain tasks during the final assembly phase, which do not exist at the beginning of the project, the budget and work load estimation require detailed studies.

6. The planning phase and risk analysis

In the planning phase the work packages and activities in the WBS are viewed against the project time scale. Every activity gets its starting and ending dates, and any relationships to other activities, e.g. one activity may not be started before another is finished etc. With sophisticated planning software in use the allocation of activities is usually seen as a rather trivial task once all the activities are listed together with their time attributes and the project calendar, with vacation and other time related information. Various network analyses are easily processed within the model and critical paths are easily detected. Reallocation and what-if analyses are also easily made. However, it is **very much harder to integrate the planning system with all the relevant technical, human resource, material management and financial data, which is crucial for detailed project follow-up**. Risk analysis should also take place in the project planning phase.

Risk management techniques have slowly moved from risk modeling, identification and analysis studies towards change management, communication and leadership studies. The fact that there are always risks, and that predicting these risks is often an impossible task, has pushed the focus more on **adjusting the project configuration to allow for risks and provide managerial tools to treat the risks in flexible manner**. The use of absolute numbers to estimate risk probabilities is of no practical relevance in everyday project management. Instead of academic methods its probably better to use simple managerial rules, such as estimating each risk and its possible removal or minimization in terms of money to provide some basis for the decision making, and to nominate a specific ‘Risk Owner’ for each major risk [10]. Each risk, its treatment and responsible people should be documented in a special “risk register” for further evaluation and control. Experience shows that **by allowing the R&D and planning phases enough time, the actual production time and risk liability will be reduced**.

To complete the planning phase for the LHC, the following subjects are to be tackled:

- *Estimate the duration and starting times of activities, and their relationship to other activities*. This will provide the first tentative plan, which can be further adjusted and tested with various network analysis methods. The time related information is obtained from the people responsible for the activities.
- *Integrate the planning system with the other systems*. A planning system alone is useless; links with the personnel and financial system must exist, and above all the activities and their tasks must be connected with the product information, i.e. the technical database.
- *Study the various sources of risks, i.e. execute risk assessment*. Possible risks concerning project environment, management, personnel or technical solutions must be listed and studied.
- *Provide procedures for risk control*. Nominate a person to be responsible for each major risk. Create risk reduction procedures through better information, risk transfer and communication. Study the sensitivity of the project plan to major risks detected.
- *Define operational planning and control procedures for the assembly phase*. The transition from preparatory to operational project management phases requires the definition of managerial principles for the everyday project control operations.

Bachy, G., Hameri, A.-P., “What to be implemented at the early stage of a large-scale project”, CERN and Helsinki University of Technology, February, 1995.

7. Conclusions

The paper has described the necessary preparatory phases of any large-scale project like the LHC. Before the planning phase the product and the site must be studied to form the work breakdown structure, which is then adjusted according to the organizational infrastructure and the available resources. The WBS is then used to build up the first plan of the project (figure 7)

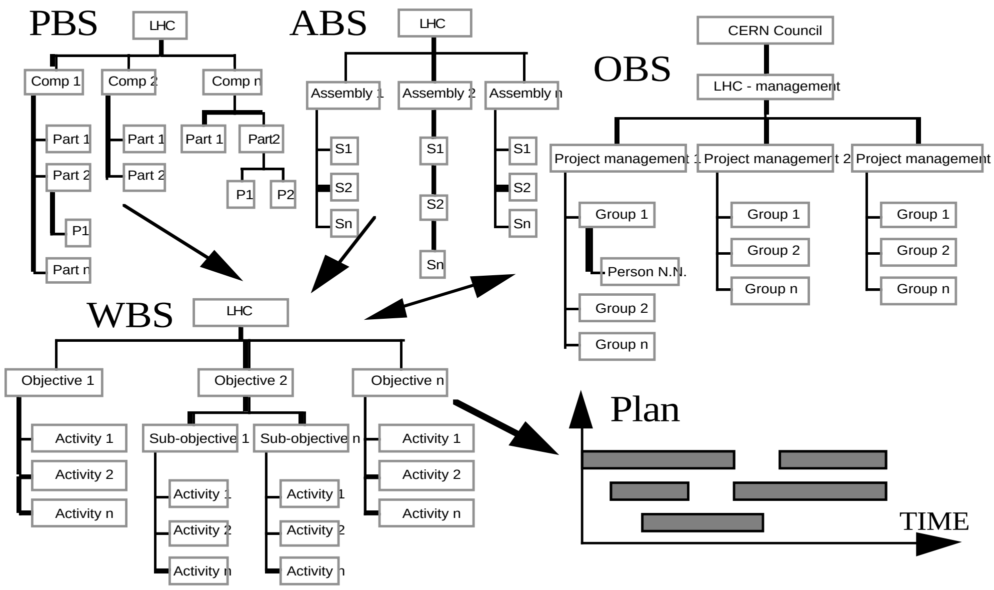

Figure 7. An overview of the preparatory processes in a large-scale project.

The paper has provided an overview of the main tasks of each phase. The underlying message is that with proper pre-planning there will be fewer problems during the actual planning phase. There are several proverbial facts stemming from the one-of-a-kind industries which should form the underlying spirit for the project management principles. These are:

- Time is money, yet, unlike money, one cannot devaluate time. Thus, time provides the key measure for progress and success.
- The product configuration must be closed before the manufacturing and assembly phases commence.
- Early commitment of the vendors paves the ground for smooth, unproblematic material management.
- Delays and long inventory and production times significantly increase the risk of damage to components and other quality defects - once properly planned the faster the better.
- Production speed correlates with good overall performance, yet the same is not necessarily valid with planning and product development.

Bearing all this in mind the LHC-management plan has to be constructed. The tight budget set for the LHC by the CERN Council implies that the preparatory phases of the project planning share the key-role in the project success.

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