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ANALYSIS OF RISK AND TIME TO MARKET DURING THE CONCEPTUAL DESIGN OF NEW SYSTEMS

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Abstract

The development of new original systems involves bridging over lack in knowledge or technologies. Such shortage, known as a "Knowledge Gap" (KG), makes it difficult to plan an R&D project with a sufficient level of confidence**.** The weakness of the current planning methods lies in their approach to the development logic. These methods presume that the sequence of events is independent of existing KGs in the project. Planning of an R&D project has to be a process of closing these KGs**.** Introduced herein is the Risk and Time to Market Analysis (**RTA**) as a method of project planning which reduces risks, development time and subsequently shortens the Time To Market (TTM).

The paper presents the concepts of R&D project planning and the new tool - Risk and Time To Market Analysis **(RTA)**, the outputs of which are: identified KGs, risks analysis and TTM indices to be used in the concept selection phase. The paper describes and demonstrates the techniques employed for each step of **RTA** application and lists the results of workshops, interviews and design laboratory experiments that validated the new method.

Keywords: Conceptual Design; Integrated Customer Driven, Conceptual Design Method (ICDM); Risk Analysis; Knowledge Gap (KG); Time to Market (TTM.)

1. Introduction

A classical repetitive project, like the construction of a building can be planned and presented in a network of known activities, with the time required to complete each activity evaluated at reasonable precision and variance levels. Such projects may be managed by common project management methods as the mature PERT [1] or the more recent Theory of Constrains (TOC) [2]. These methods are used to outline a network of activities where the logic interlinks are represented, to evaluate the time each activity will require to complete, to identify the critical path determining project length and to take measures as required to identify and correct deviations and overruns. The variable factors in the management of a project are the actual implementation times and resources availability. The assumption is that the network of activities remains static throughout the project life cycle. The risks associated with a project of this kind are mostly due to unexpected schedule overruns or to shortage of resources required for timely implementation.

In a development project that includes new modules or components, the Knowledge Gaps - KGs that exist make it difficult to foresee what development activities will be required, how they will be interlinked, whether a certain activity will be accomplished successfully or require further actions to complete, and, obviously, how long it will take to implement the project and what resources it will need. **A proper planning of an R&D project must be a process of closing the Knowledge Gaps**.

1.1 The Bonen scale of R&D Knowledge Gaps

Preliminary analysis of KGs in R&D projects was first introduced by Bonen [4], who classified design modules into four categories by the level of KGs they represented and established the number of development cycles required for completion as demonstrated in Table 1. A **development cycle** means a set of activities that is performed in order to advance the maturity of a system, subsystem or part and eliminate the existence of KGs. Such cycle is composed of three steps: **Design**, **Build** and **Test,** in certain cases by early simulations.

Table 1: The Bonen Scale of Knowledge Gaps in R&D Projects

Level	Definition	Description	Development Cycles
1	**Revision** or **Variant Design**	The project team is familiar with the solution (which has already been accomplished in-house), however small revisions are still required	1 to 1.5
2	**Engineering Gap** or **Adaptive Design**	The project team knows what to do and is familiar with the solution, however a major R&D effort is required	2 to 3
3	**Original Design** but Viability proof exists	The project team knows that a solution is feasible and that the technology exists somewhere, however the team does not know how to attain such a solution since it has never been attempted in-house before	m + 2 to 3
4	No Viability proof, **Research**	The project team does not know whether a solution is possible, or an appropriate technology is available, research is required	??? + m + 2 to 3

Project development milestones represent moves down the KG levels, with an effort made to remove major uncertainties as early in the process as possible and at minimum expenses. According to Bonen, at level 4, an unknown number of development cycles is required to move down to level 3, therefore no project can include a level-4 component. Such components are covered under a separate research effort before the project starts.

At level 3, m development cycles are required to secure a solution and move down to level 2 so no more than one or two level-3 components should be included since such components determine the project's duration and cost to complete. Level-3 components may only be risked if they contribute greatly to major system performance parameters. The work on level-3 components should be started before any of the other components are developed and high risk components should be backed up with solutions of a lower risk level.

Bones claims that the minimum level of integration is that of the component with the largest KG. And that too many level-1 components indicate a product offering no novelty and should raise doubts regarding customer interest in such a product.

1.2 The "Top-Down design, Bottom-Up realization" concept

For system's R&D activities to be accomplished at minimum risk, they should be planned serially starting with the system level design and proceeding through modules, parts and mechanisms. On completion, production documents will be prepared, the production line replenished with equipment and 1st lot production started. However, the need to penetrate the market ahead of the competition, requires that some activities will be pursued simultaneously. This packing of simultaneous activities together produces logic links which dictate a minimum requirement to start any stage subject to the extent of willingness to risk an attempt at this stage before all the information has become available and all KGs and risks as associated with the previous stage have been eliminated.

Although simultaneous development processes are sought as shown above, such effort is limited by the "Top-Down design, Bottom-Up realization" concept of system development [3]. The Top-Down approach serves to ensure that customer requirements are reflected in product definitions and in the solution offered in response to the specification, that each hierarchy in the system matches the one above, that the interface between system components is properly planned, and that the integration of all parts yields the result expected of the product. A Top-Down plan starts with the definition of the system and total concept at the top hierarchical level and proceeds to derive requirements and data for the levels below.

The Bottom-Up realization approach ensures that each level in the hierarchy provides to the hierarchy above good parts which meet their specification requirements. A Bottom-Up realization plan starts with a detailed design of the lowest hierarchical level, based on which the details of the level above may be realized.

Product development must be based on these two approaches concurrently. The concept of moving in both directions clearly holds up the development process and creates a logic which must be considered during project planning.

1.3 ICDM – Integrated, Customer Driven, Conceptual Design Method

A few prescriptive methods for the conceptual design of a new product have been introduced. **ICDM**, Integrated Customer Driven Conceptual Design Method, is one such method that has been introduced by the authors, and which has been in used extensively throughout the Israeli Hi–Tech industry [5]. Analysis of the many potential concepts generated and selection of the winning concept are accomplished (in step 8 of ICDM) with analysis and improvement tools as CFMA (Conceptual Failure Mode Analysis) [6], CDTC (Conceptual Design To Cost), and now the third tool **RTA** (Risk and Time to Market Analysis) as introduced here.

2. Risk & Time to Market Analysis (RTA)

This concept of project planning based on identification and closing of KGs allows development of a tool which can yield the following outputs: identification of KGs and analysis of project risks, planning of the development process as required to close the KGs and reduce the risks, evaluation of the TTM as required for comparison with the alternatives, improvement of projects' TTM. The method presented herein is accomplished in five steps as listed and described below. The basic steps in RTA planning are also shown in Figure 1.

2.1 Step A: Characterization of the Knowledge Gap (KG) and Risk

This step is implemented through the use of a KGs/ risks chart as illustrated by Table 3, with columns as listed below:

KG/ Risk Description associated with a function or with an interface between functions, as follows: **Function gap** – where there is a KG concerning the implementation of a function or where there is uncertainty regarding the capabilities of the solution selected. **Interface gap** – where there is a KG or uncertainty regarding the effect of one function on another one or on the performance of the complete product. The KG is described briefly and concisely, e.g. "knowledge of a mechanism capable of separating paper sheets"

Sources of KG/risk – the exact point of the gap, e.g. product usage, field application, user environments, customer preferences, user friendliness, product storage, miniaturization technology, required investment, theoretical progress etc.

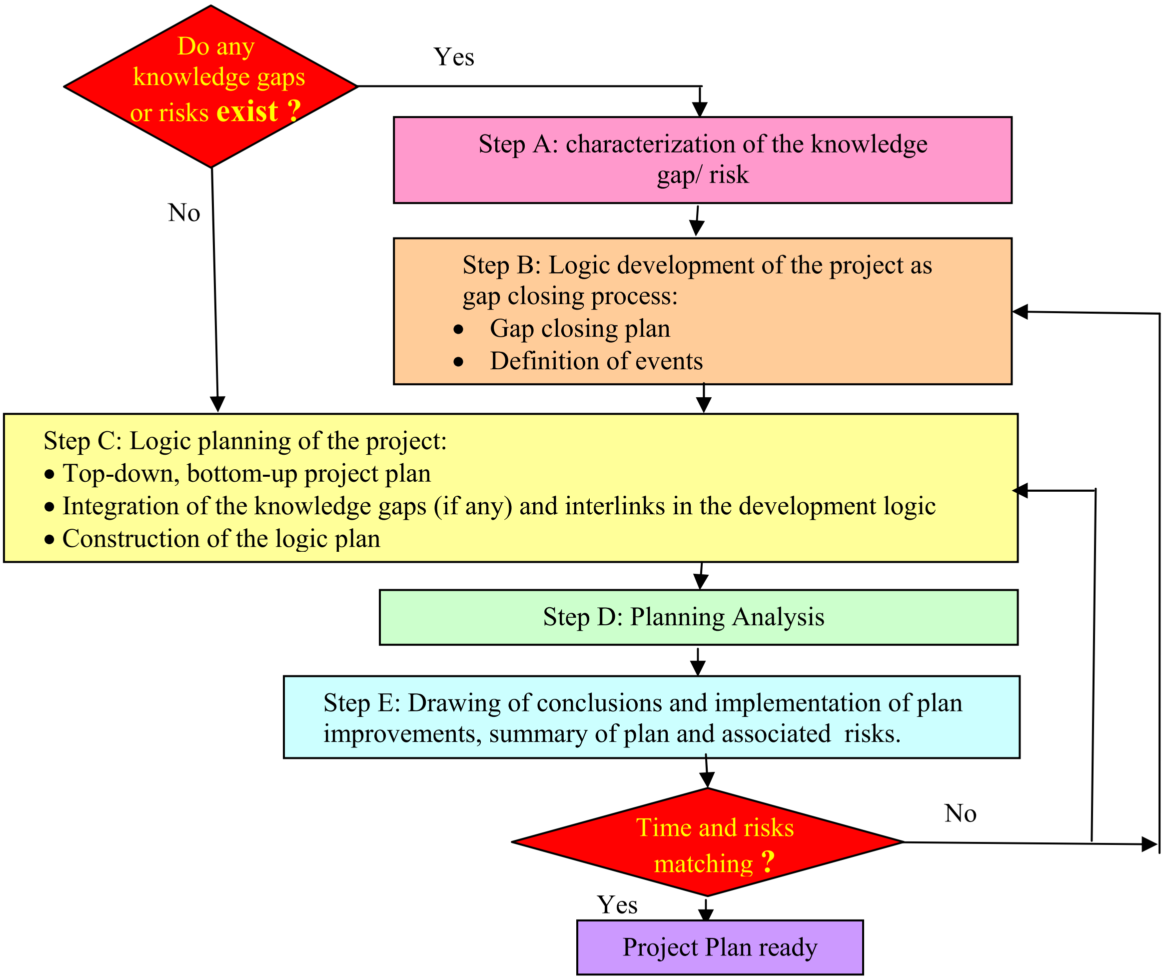

Figure 1: Basic Steps in Planning by the RTA Method

Table 3: Examples of Knowledge Gap/ Risk Definitions

KNOWLEDGE GAP/ RISK DEFINITIONS TABLE				RTA Stage A		
Project: Flashlight for the Elderly				Date: 12/12/02		
Team Members: Abraham, Isaac, Jacob, Reuben, Simon, Levi						
No.	Knowledge Gap/ Risk Description	Sources	Failure Description	Severity Level	Gap Level	Criticality Level
1	Ability to attain high capacity at low volume	Batteries technology	Insufficient capacity or oversized flashlight	II	2	M
2	High light intensity in a small bulb	Bulb technology	Low intensity	III	3	H
3	Integration	Interface between parts	Will not function together	III	3	H
4	Customers response to a disposable flashlight w/o on/off switch	Customer preference	Market loss	IV	1	M

Failure description of what may happen as a result of failure to close the gap or on realization of the risk, e.g. "flashlight of low illumination power" or "market lost".

Severity level– a semi-quantitative description of the failure on a scale as defined by the team by the nature of the problem. Table 4 is an example of a failure severity scale.

Table 4: Example of A Failure Severity Scale

Severity Level	Numerical Value	Significance
None	I	None (e.g. risk eliminated or gap closed)
Minor	II	Inconvenience, extra costs
Major	III	Unsatisfactory performance or market share, financial loss
Critical	IV	Product task failure, market loss, safety event, company existential danger (bankruptcy, catastrophic lawsuit)

KG Level– a semi-quantitative estimate of the KG based on the Bonen scale

Criticality level– combines the failure severity with the KG level and indicate the priority of the risk reduction and gap closing activities. Table 5 is an example of a risk criticality scale.

Table 5: Example of A Risk Criticality Scale

Risk Severity		Risk Criticality Level			
None	I	L	L	M	M
Minor	II	L	M	M	H
Major	III	M	M	H	H
Critical	IV	M	H	H	H
L = Low		1	2	3	4
M = Medium		Revision	Eng. KG	Original	Research
H = High		Knowledge Gap			

2.2 Step B: Logic development of the project

In this stage the R&D logic is developed. Using a gap closing plan such as Table 6, main events in the life cycle of the project are identified, and subsequently defined and analyzed for configuration and for contributions to closing of the KG using a table such as the one illustrated by Table 7.

Based on the KGs, the logic of planning has to be based on the number of needed development cycles, and start with the longest. This type of planning is basically a **KG closing plan**. Each such cycle reduces the risk by a certain amount, and the number of cycles needed to eliminate the risk depends on the level of the part in the Bonen scale above, or the severity of the KG. A level 1 sub-system needs one such cycle with a possibility of a short additional second cycle, see table 1 which applies to systems, but also to subsystems. A level 2 sub-system will require 2 or more development cycles. Each subsequent cycle lasts less than the previous, as only a few parts of the development have to be updated.

The **gap closing plan** serves to identify central events in the R&D project. A central event is such which represents closing of one or an entire group of KGs. Central events may be an early design cycle, experiments, demonstrations, assemblies, tests, design reviews or production line startup.

KGs are listed as defined in the KGs definition table (see table 6). Against each gap, major activities as required to close it are listed under the gap closing measures column. Then, a vertical line is drawn which connects activities which may be pursued simultaneously. Table 6 illustrates three such central events: a preliminary design review (PDR) in summary of all

Table 6: Example of a Gap Closing Plan

GAP CLOSING PLAN Project: Flashlight for the Elderly Team Members: Abraham, Isaac, Jacob, Reuben, Simon, Levi			Date: 12/12/02							RTA Stage B1
No.	Risk / Knowledge Gap Description	Criticality Level	Risk Reduction / Gap Closing Measures							
1	Ability to attain high capacity at low volume	M	Power analysis	Battery design	Construction of battery models	Lab tests	Environmental robustness tests	Integration in product	Usage scenarios tests	
2	High light intensity in a small bulb	H	Light intensity analysis	Bulb design	Construction of Bulb models	Lab tests	Environmental robustness $ lifetime tests	Integration in product	Usage scenarios tests	
3	Integration	H		flashlight integration design	Flashlight lab integration		Environmental robustness tests	Flashlight integration	Usage scenarios tests	
4	Customers response to a disposable flashlight w/o on/off switch	M	Interviews with customers					Construction of complete flashlight models	Market tests	
5	Reduced performance, low risk, back-up battery and bulb	L		Parts design	Construction of battery models	Lab tests	Environmental robustness tests	Integration in product	Usage scenarios tests	
			PDR							
Completion of components and structural design (Preliminary Design Review)					Prototype integration					
				Construction and integration of a prototype						
							Market tests			

Table 7: Examples of Event Definitions in a Knowledge Gap Closing Plan

EVENTS DEFINITION Project: Flashlight for the Elderly Team Members: Abraham, Isaac, Jacob, Reuben, Simon, Levi			RTA Stage B1 Date: 12/12/02	
No.	Event Description	Components Participating	Event Element Configuration	Event's Contribution to the Knowledge Gap/ Risk Elimination
1	Power analysis	Batteries	A computerized model of batteries behavior at given volumes	Suitable capacity demonstrates attained at the required volume will reduce knowledge gap 1 to level 2.
2	PDR	Batteries, bulbs, structure, integration, backup batteries and bulbs	Draws and analyses of the system components and their integration	If the designs approved and the analyses prove capability, knowledge gaps 1,2 will be reduced to level 1 and knowledge gap 3 to level 2
3	Lab tests for batteries	Batteries	Prototype models as provided by the supplier	If the prototype models meet the functional requirements, knowledge gap 1 will be reduced to level 1.
4	Usage scenarios tests	Complete flashlight with package	Final flashlight prototypes, preferably from the production line	For flashlights off the production line, successful completion of market tests will lead to final closing of knowledge gap 4
6	System lab integration & functional lab test	Complete flashlights	Initial models of structure, batteries and bulbs; backup batteries and bulbs	If the prototype meets the functional requirements, System knowledge gap (3) will be reduced to level 1 or 2; Knowledge gaps 1, 2 will be reduced to level 1
7	Market tests	Complete flashlights	Flashlight models of design similar to that of the final product	Customer acceptance of the proposed flashlight will reduce knowledge gap 4 to level 1 or eliminate it entirely.

design activities, integration of the first prototype, and market tests. Planning also includes backup activities for the development of reduced performance, lower risk components in the event of failure of the main development path.

Definition of events for each event identified under the gap closing plan , whether comprising multiple activities or a single activity, is represented by a row in the event definitions table as illustrated by Table 7. For each event, those system components are listed which are to take part in the event, along with component configurations. Configurations may relate to hardware components, in which case they will represent component's level of maturity (model, prototype or a part off the production line), or to products such as computerized models or drawings. Also described for each event is its own contribution to closing of the KG or to the reduction of the risk, based on the results of the event. This column, listing event's contribution to closing of the KG, is highly important to the understanding of the project's logic. It would indicate the actual need for the activity, identify another possible activity covering the current stage for the same KG, point out additional activities required before the current one to increase its probability of success, and show whether or not the method selected is the best one possible in the effort to close the KG or reduce the risk.

Tables in the form of Tables 6 and 7 allow a clear view of the development plan logic and how it drives the project into closing all KGs fully. Such presentation of the activities also allows for plan improvement through merging of multiple activities such as inspections and tests, or through elimination of redundancies in handling of the same KG. At this stage, the team can already identify the logic links among the various activities in preparation for the next stage where project's logic plan is pursued.

2.3 Step C: Logic plan of the project

Now a logic plan for the project is constructed. It includes the data required to set up the project's network of activities, describe these activities and interlinks thereof.

Development of any product comprises activities at multiple levels. Figure 2 illustrates a basic plan of a simple system, which comprises two levels of integration (the system level and the parts and mechanisms level), with KGs as defined in table 3. At any level, each development activity comprises three elements: design, realization, and tests and demonstration. The events that were defined in tables 6 and 7 are located now in the project logic plan.

Figure 2 illustrates a project development plan listing simultaneous activities run at certain controlled risks. The vertical arrows represent logic links reflecting minimum requirements for starting activities. As shown, the ability to reduce times and to work simultaneously is a function of the willingness to take risks. In the example of Figure 2, parts for the first lot are procured on preparation of a parts list which may be constructed immediately on completion of the first prototype of parts and mechanisms and before they have been tested – and certainly before they have been demonstrated through system tests.

The KG is translated by the Bonen model into the number of development cycles required to close it. Therefore, each development activity starting with a KG level higher than 1 will be represented by a serial sequence of the number of development cycles allocated to it. The logic plan must obviously cover all the activities and events defined under the gap closing plan. The links among the activities will be derived from the project logic plan based on the project development logic, on the Top-Down, Bottom-Up concept and on the links defined by activity and event definitions.

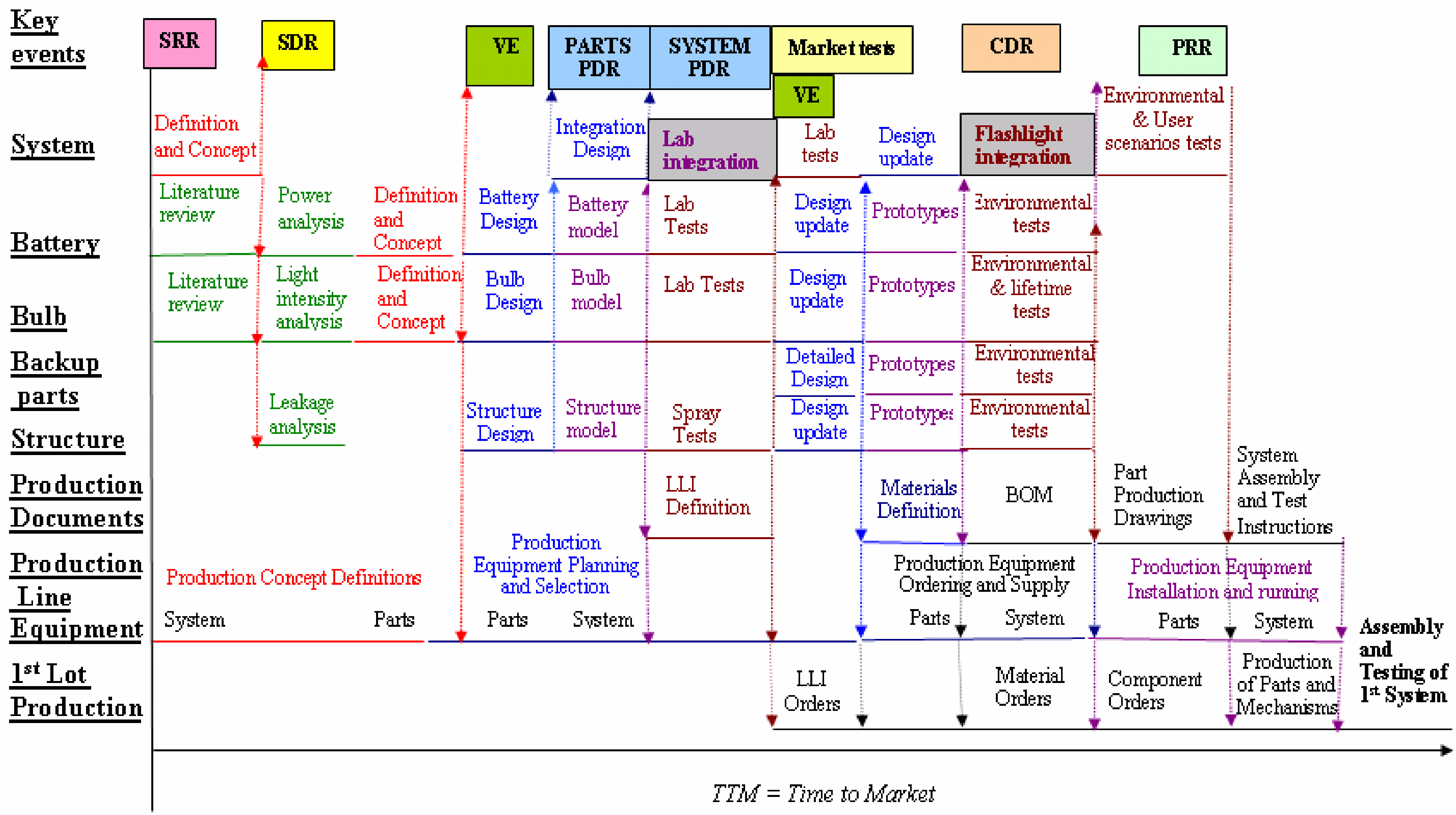

Figure 2:An example of a Logic Plan of a Project with Two Levels of Integration and with Knowledge Gaps

2.4 Step D: Plan Analysis

This step is derived from the logic plan, and it is when the logic network is analyzed on entry of time estimations. Starting this stage, any project management method may be employed – the mature PERT [1], the more recent Theory of Constrains (TOC) [2], or any combination thereof. These methods are used to construct a network of activities where the logic interlinks are represented, to evaluate the time each activity will require to complete, to identify the critical path determining project length and to take measures as required to identify and correct deviations and overruns. Currently, these methods are implemented through the use of such dedicated software programs as MS Project (for PERT) or Concerto (for TOC). Algorithm calculation instructions are listed in the literature and will not be quoted herein.

2.5 Step E: Conclusion drawing and plan improvement

At this stage, conclusions are drawn from the analysis accomplished in the previous stage. Decisions are made regarding technical, conceptual and logic changes, and such which will allow unlinking, selection of solutions with fewer cycles or smaller variance, revaluation of time estimates, allocation of resources as required to reduce cycle times and control of compliance with the time schedules – all of which will ensure that schedules are met and the products are offered on the required TTM. On a decision to implement changes and improvements, stage C or D are rerun to revise the data and recalculate the algorithm and finally, a plan summary is prepared which describes the conclusions drawn and the decisions made in the previous stage, the risks taken to reduce schedules, along with risk contributions to such reductions and the gap closing and risk reduction process, remaining risks, control measures and recommended action items.

3. Application of the RTA method to the conceptual design

The project planning activity is run for each alternative at the stage of planning and analysis of concept alternatives. At this point, little is known and the level of detail and the time invested must be limited in advance, with the suitable limit normally amounting to several tens of activities and no longer than one half day to one full day per concept. In the technical phases, an expert and a suitable software program should be employed.

ICDM (including RTA) contribution was evaluated through workshops, interviews and design laboratory experiments. Some 500 designers participated in special workshops where they were introduced to the methodology and experienced it to some extent. Questionnaires were used by the designers to express their views on the contribution of the methods to the conceptual design effort. Analysis of the responses shows that customers satisfaction from TTM and risk was increased by 18.2% as a result of ICDM application and that the number of engineering changes introduced during subsequent design processes was reduced by 40% to 50% and the TTM by 30%.

4. Summary: Risks and Time to Market Analysis for an R&D project

Presented herein is a method by which R&D projects may be planned and project risks and times analyzed. R&D projects differ from any others by the level of knowledge possessed by the project team at onset. R&D projects are characterized by KGs which make it difficult for the project team to evaluate what development activities will be required, how they will be interlinked, whether a certain activity will be accomplished successfully or require further actions to complete, and, obviously, how long it will take to implement the project and what resources it will need. Planning of an R&D project thus plagued with KGs is a process by which these gaps are closed.

Described herein are the concepts of R&D project planning and a method of project risk and TTM analysis – RTA, which is implemented in five steps:

Step A – Characterization of the KG or risk.

Step B – Logic development of the project

Step C – Logic plan of the project

Step D – Plan analysis.

Step E – Conclusion drawing and plan improvement

The RTA yields a development plan, identified KGs and analyzed project risks, TTM evaluation as required for comparison of the alternatives and improved project TTM.

The respective contribution of **ICDM** and **RTA** were evaluated through workshops, interviews and design laboratory experiments. Analysis of the findings shows that customer satisfaction with the TTM and risks has been increased as a result of **ICDM** and **RTA** application, and that both the number of engineering changes introduced during subsequent design processes and the TTM can be significantly reduced.

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