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DESIGN ENGINEERING PROCESS FROM CONTENT-BASED POINT OF VIEW

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1. Introduction

Design is a multifaceted process and therefore design research must be multidisciplinary. Design is, essentially, an organizational activity in which both group work and individual thinking are involved. Design consists of various types of engineering activities, which can be investigated and explored, and is studied under various labels such as Applied Engineering Design Sciences, for example. During last decades to this engineering research tradition has been added a human-centered perspective. Naturally, these two fields of research, traditional design analysis and human-oriented investigations to design are not without connections. In fact, they must closely interact in order to recognize the decisive role of individual engineers in the actual design processes (Nevala 2004, 2005a,b, Nevala and Karhunen 2004, Saariluoma 2003, Saariluoma, Nevala and Karvinen 2005 a,b, Simon 1969). This paper emphasizes the applied engineering design science perspective.

A new way of looking human role is offered by content-based approach, in which explaining real-life design processes is based on the analysis of designers' mental contents (Saariluoma 2003, Saariluoma and Maarttola 2003). Recently, this approach has been developed from theoretical beginnings to an analysis of industrial scale design engineering processes (Saariluoma, Nevala and Karvinen 2005, Nevala 2005a,b). The fundamental idea is that in order to understand design process properly it is essential to approach it through the thought processes of individual engineers engaged in the process. Individual engineers are the only perpetuating force in engineering design. While engineers work in teams, groups and within organizations, they still remain individuals. The total process is guided by the thinking and interactions of individuals. However, investigating human role in design is a difficult task. Content-based analysis provides us with objective means for assessing the progression and results of the engineering thought processes involved. We have reconstructed an industrial scale product development process. Empirical investigation was performed at Metso Paper Inc., Jyväskylä, Finland. The target case was the development of the so-called extended nip press (ENP) for paper and board machines 1983 – 2003. The reconstructive documentary material together with the interview statements of the key persons constitutes the scientific data for our content-based analysis (Nevala 2005b).

This paper provides a brief introduction to the empirical case and summarizes the methods of our reconstructive content-based analysis. Furthermore, we discuss briefly the notion of "task definition window" and the organizational dimensions of it.

2. The case: extended nip press (ENP)

The target process is the development of the extended nip press ENP for Valmet /Metso paper and board making machines 1983 – 2003. This has proven to be one of the most successful innovations in improving the press section of paper machines in the last century. Today it is known as Metso SymBelt Press, by its trade name. ENP provides a wider contact zone (i.e. the press nip) between two rolls and consequently a longer press impulse on the fast running paper. The lower roll has a flexible mantle, which is pressed by the upper roll against a contoured “press shoe” inside the lower roll (Figure 1).

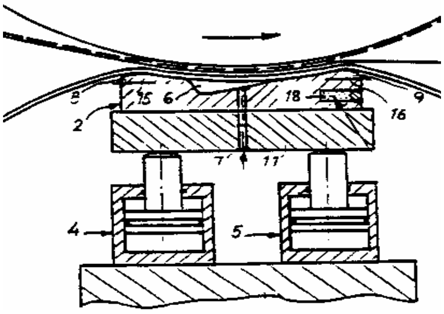

Figure 1. Extended nip press ENP: schematic illustration of the principle of Metso SymBelt press. Source: Finnish patent application no. 963702/3.8.1995; reprinted by the permission of Metso Paper Inc. and the inventor

The idea of an extended press zone in the dewatering presses of board and paper making machines is old. The proposal to increase the press impulse for better water removal seems quite natural. However, there have been many obstacles preventing utilization of the idea. The problems have been mainly techno-economical, consisting of both facts and beliefs. First of all, up to the end of 1970s the technology was lacking – or was believed to be lacking – reliable means to flexibly support the wet paper web through the extended nip zone. The culmination point of the history of ENP was the delivery of the first production scale open-belt “shoe press” for a board making machine in Springfield, USA 1981 by Beloit Corporation (USA). This breakthrough alerted the other paper and board machine producers, and this is the starting point of our inquiry as well. Figure 2 summarizes the ENP development at Valmet/Metso Paper Inc. between 1983 – 2003.

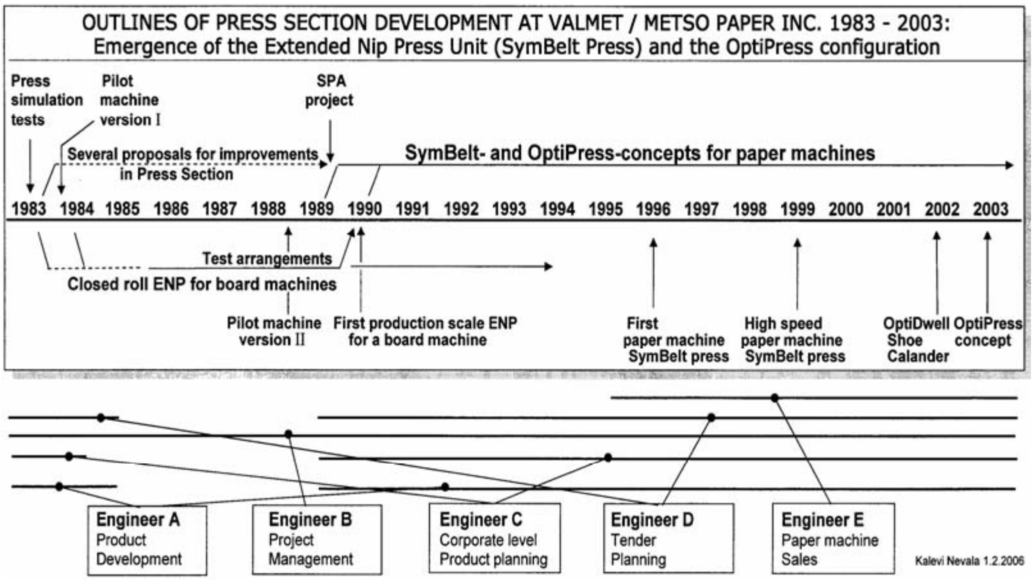

Figure 2. Outlines of Valmet/Metso ENP developmen

3. Research method

3.1 Content-based analysis

The approach to the empirical case was based on the principles of content-based thought research (Saariluoma 1995). Saariluoma developed the theory of content-based analysis first in the context of chess and applied it later in many economical environments. The first application of the content-based analysis in an industrial-scale design engineering process is reported in Nevala (2005b).

The very essence of the content-based thought analysis is to understand the inbuilt logic of the domain of interest. Different conceptual domains have different functional systems, which guide the flow of thoughts. It is therefore necessary first to analyze and explicate the structures and types of the domain specific knowledge, the involved concepts, their attribute structures and the domain specific characteristics of the rationale for making design decisions. However, this is not an easy task. Section 3.2 below describes our reconstructive method in coping with the difficulties involved.

3.2 Reconstructive method

The time span of the target process is over twenty years. It was launched in 1983, and is still on-going. This means that the only realistic way of approaching it is reconstruction (Saariluoma, Nevala and Karvinen 2005a,b), which we, in fact, carried out during 2003 - 2005 on three levels. First, a reconstructive data about the real hardware level changes of Valmet/Metso paper machines were gathered. Second, the advancement of the plans for developing the paper machine press section during the period of examination was documented. Third, the relevant information of the hardware and plan level reconstruction was combined with the interview statements of individual engineers in order to get a idea of what really had been thought during the long product development period. The central characteristic of a real-life conceptual reconstruction is its multifarious complexity. There is no sense in trying to construct an all-inclusive model in detail. Thus far it has been possible for us to put up only a fraction of the total reconstructive model of the conceptual and ontological structures behind Metso SymBelt press (Nevala 2005b).

The techniques of data collection were designed for the purpose of building a consistent reconstructive model of the ENP-development process. In several group interview sessions, the history of Valmet/Metso Paper Inc. development work on wet pressing 1983 – 2003 was recalled by the participants. In addition, most important events and strategic decisions were recollected, detailed information about the state of global papermaking technologies and company know-how were discussed and the propositions for further improvements were reconciled. Organizational data, engineering handbooks, writings in professional magazines, patent publications, etc., which were recommended by the interviewed engineers, were gathered.

The interviews were designed to be unstructured dialogues between experts of paper machine technology. In the first sessions only the main theme was stated. Later on more focused questions were asked, and the final queries were effected by phone and by email. Document analysis was then employed to confirm the interview statements and to direct the focus of the researchers.

In addition, many so-called “peripheral details” were checked out. This kind of information, even though it has no immediate connection with the interview statements, is very important in assessing the total field of knowledge, which constitutes the frames and contents of the domain specific engineering thinking. For example, many details of the history of papermaking, including physical details of the paper web formation (e.g. the role of so-called chemical hydrogen bonds between cellulose fibers and water molecules), and the organizational arrangements between Valmet, Tampella and Rauma-Repola which resulted in the founding of Metso Paper Inc. in 1999, and even the sudden bankruptcy of American Beloit Corporation in 1990s, which resulted in a global redistribution of paper machine manufacturing business, are all examples of important background information, with which the individual engineers are working. A major part of this information will never be explicated. It remains mainly unspoken, but, nevertheless, this kind of information is a significant factor in engineering thinking. Insightful understanding of this background information is essential in reconstructing the engineering thought processes. (Nevala 2005b).

4. Empirical results

The acquired empirical material proved to be a very versatile set of data. It allows explaining and interpreting the investigated design and thought processes of the centrally involved engineers on the basis of conceptualizations from many different perspectives. Some of these interpretations are presented in our earlier papers (Nevala 2003, 2005a, Nevala and Karhunen 2004, Saariluoma, Nevala, Karvinen 2005a,b) and in the summary part of Nevala (2005b). One example of the interpretations is the four-mode model of thinking: it starts from a self-consistent mental representation produced by the apperception process and advances through restructuring and reflection, finally to integrate a new consistent mental representation through the constructive mode of thinking. The modes of thinking are not necessarily chronological. They can overlap or they can even be nested within each other.

In this paper we examine the characteristics of the new notion of "task definition window" and discuss briefly its utilization in revealing the organizational aspects of design.

4.1 Characteristics of individual task definition windows

One of the central findings which came up from the analysis of the empirical material was that the thinking of individual engineers was characterized by frames and constraints set by the organizational position and current assignment. Organizational position determines the perspective from which the engineer looks at the process s/he is engaged in. The current assignment in turn directs the focus of thinking. The focus can be changed as necessary. The engineer can scan and zoom into or out of the focus areas of the view. It can be thought that the engineer looks at the task environment and the object of design through a restricted "window", which, however, is movable and can comprise large entities or be focused to the tiniest details. The content elements of the "view" within the window are respectively either large entities or focused details. The engineer defines the current task within these frames and the task definition embraces an appropriate degree of detailed knowledge.

When the frames of the current task are fixed, the four modes of thinking come into play in processing the contents of the task. (1) An active self-consistent mental representation of the task situation is generated by the process of apperception in the mind of the engineer. (2) Concurrently the mental restructuring process of the trained engineering mind uncovers possible inconsistencies in the representation. (3) The reflective mode of thinking searches new solutions to clear away the inconsistencies. (4) The constructive mode integrates new elements to the representation in order to achieve an acceptably consistent representation of the final solution. According to our empirical material an essential reinforcing element of this design thinking process is sketching by pencil on cross-ruled paper. Sometimes these modes can process a solution to the inconsistencies very quickly, sometimes they form iterative cycles, and can take years, even decades, to be completed. The final construction is then a result of many individual constructive mental processes; in industrial scale often of thousands of individuals. The four modes of thinking process all types of content elements.

In the following paragraphs we present two examples of the extreme ends of the range of the content elements of task definition windows, which the engineers having different assignments in the same design engineering process had to deal with. The first example is from the corporate level business planning, which can be thought of as an essential part of design engineering process as it provides the base for the strategic planning and decisions directing and focusing the rest of the product development process. The second example is from the other end of the scale: a detailed design of a completely new key component for the ENP construction. Between these two extremes our empirical material covers several additional perspectives regarding the investigated process: testing activities, constructing the ENP unit, generating model configurations of the press section, tender planning of the press section, paper machine sales activities, etc. However, the space restrictions of this paper do not allow us to present all the examples.

Example 1: This example refers to arguments of reasoning in corporate level business planning, which is the foundational phase of product development. The following quotations are extracted from the interview protocol CD, starting from (Track10: 00h,38min,35sec = T10: 00,38,35):

Question: This is interesting… this search for new things… For the business it would be convenient if the established solutions could be applied… But it doesn't work that way?

No, it doesn't. …Competition with the products becomes such… that the products in the world will be ultimately produced by those who can produce them cost effectively… Profitability of such products fades gradually out…And new solutions must be developed…

Q: But how is this search for new things accomplished …?

Today the way of looking at these questions is that… we try to discover how the world will change… scenarios are used… We are looking for possible futures… different futures… And then we think how these would affect the paper industries… and packaging industries… Today we have these both in our hands… What kinds of profitability problems are those that are caused to these industries…? From there on we start to ventilate the situation and consider what to offer… What the technology could offer… These are the kinds of things we try and match together…

With these scenarios we collaborate with paper industries… and manufacturing industries as well… the methods have evolved there considerably… We look broadly [at the problems and opportunities]. One method is called PESTE, which comprises Politics, Economy, Social aspects, Technology and Environment… Additionally we have also Demographics, the population development…

Further (T10: 00,52,48): *… Our goal is so-called robust strategy… it fits to all possible futures… [The interviewee shows the slides of Fig 3]… And then the key drivers… take for example the cost of energy… what is its influence... And where there is water, where not… These kinds of things... these kinds of matrices we put together... This leads up to strategic planning…*

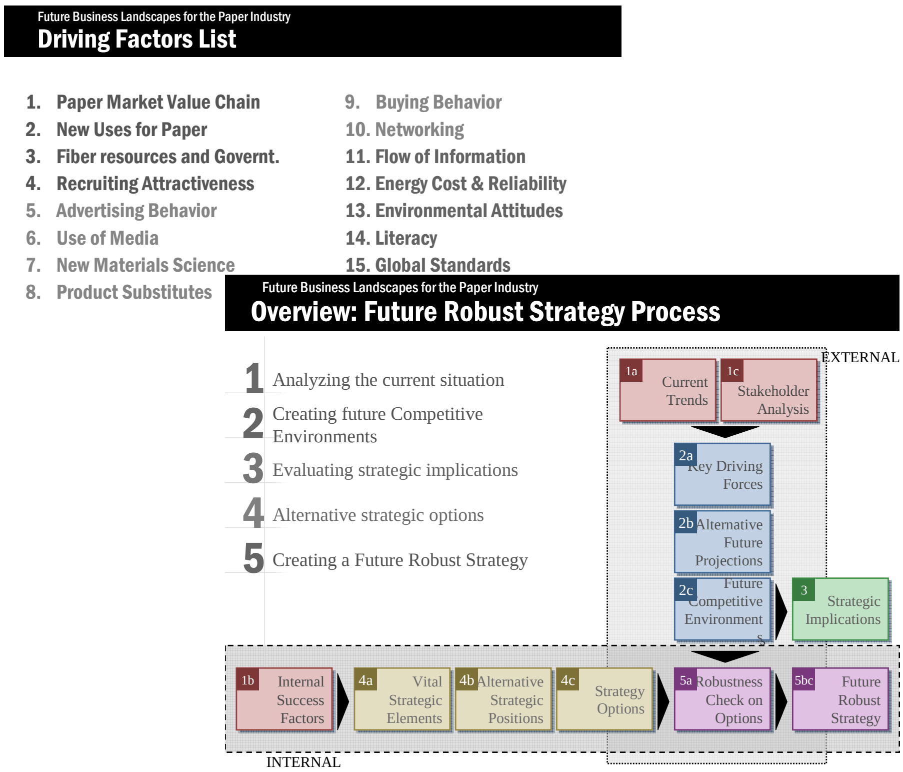

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Figure 3. Content elements of task definition window of engineer C. Reprinted by the permission of Metso Paper Inc. and Alan R. Procter, ARP Inc. and Oliver Schlake, Stravigant LLC

Explanation: The above quotations and the topics of Figure 3 give good indications of the considerations, task definitions and even of the planning methods on the business planning level. The frames of this window are broad. The perspective is global. The broad task definition is to assess what are the possible changes of the world pertaining to paper consumption and production and how to cope with these changes. The central tools are scenarios (Figure 3). The thoughts thus processed are large entities. Details of the entities are not processed intentionally, but the empirical material reveals that conceiving the realistic possibilities of implementing necessary equipment in a mechanical-engineering way always forms part of the reasoning of this engineer, at least on the background (Nevala 2005a). The sound professional background and operational knowledge of the organizational culture has built up the confidence on that "if I can work out the principles of a functioning process, the engineers will solve the practical problems".

It is vital to understand that this level is an integral and literally decisive part of design engineering process. The analysis of the content elements of this level reveals the underlying reasons for product development and design strategies and can help to manage the change.

Example 2: This example presents task definitions in the design of the details of the most essential component of the SymBelt press, namely the hybrid press shoe (Figure 4f).

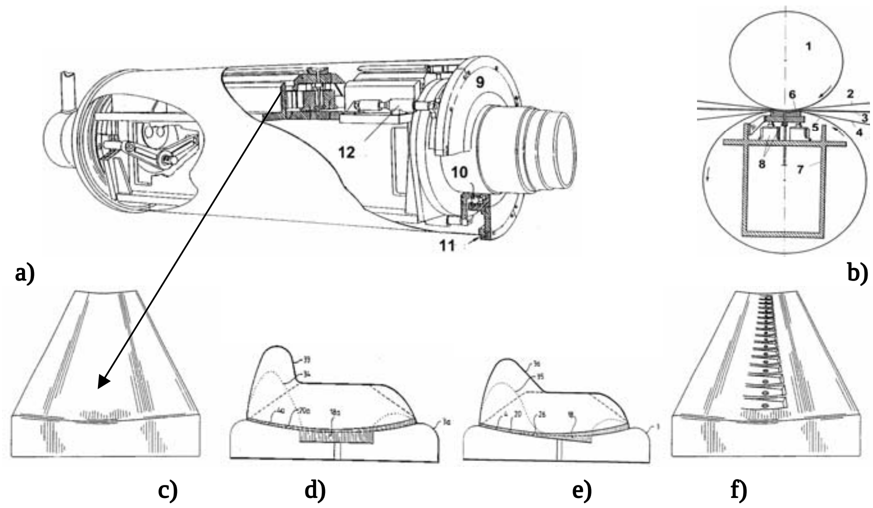

Figure 4. Illustrations of some central content elements of the task definition window of engineer B: a) construction of the SymBelt roll, b) schematic illustration of ENP unit, c) hydro-dynamic press shoe, d) first approximation of hybrid press shoe (includes hydrostatic pressure pocket) and its pressure distribution, e) and f) final design of hybrid press shoe. Sources: Patent publication PCT, WO 91/17308 and US Patent 5,997,695, figure is edited by Kalevi Nevala; reprinted by the permission of Metso Paper Inc. and the inventor

Quotations starting from (T16: 00,13,19):

Q: What viewpoints did you have about the shape of the hydrodynamic shoe?

…We had already studied what the shape of the shoe should be in order to act as a hydro-dynamic bearing. We confirmed the right contouring by tests… The radius of the concave part of press shoe was established by thinking that the radius of the counter roll [1 in Figure. 4b] plus the fabrics, plus something… It must be greater than the radius of the counter roll… We did not calculate anything in this stage… by a good engineering guess 2 – 3 mm greater radius… … Then there were also the support of the shoe, the longitudinal stabilization of the shoe beam, the hydraulic system, etc.…

Further (T16: 00,17,05): *… One thing was this [the hydrostatic pressure pocket in Figure 2d]. This we had to think about particularly, because it was a new invention… Certain amount of pressurized oil was supplied [into the pressure pockets] by a fixed pump… The test arrangement was built and test carried out and immediately it was seen that it [the hybrid shoe, Figure 2d] works [better than the hydrodynamic shoe, Figure 4c]… the justifications were that friction was* *lower, power consumption low and temperature rise and temperature profile of the belt were OK… It was measured by a thermographic camera to be about 60 degrees centigrade… Oil film thicknesses and pressure profiles were measured and the conclusions were positive: all features which were sought after could be established…*

(T16: 00,19,27): *... There was one thing not that straightforward… Here [Figure 4d] there was no chamfer… Only after a few months of tests it was noticed that a fiber flock on the paper web frequently made a hole to the belt [when it struck on the sharp edge of the pressure pocket]… Consequently, the pressure pocket was reshaped (Figures 4e and f)…*

Explanation: In this example the task definition was focused on a small but essential detail of the whole construction. In this case the task definition window was restricted to the interface between the press shoe (Figure 4b, items 6, 4c and 4f) and the counter roll (Figure 4b, item 1) and specifically to what took place between the press shoe and the flexible roll mantle – the belt (Figure 4b, item 5). However, the quotation reveals also that the engineer surveyed flexibly all relevant tasks related to the press shoe.

The interview statements (Track 16 on the interview protocol CD), from which the above quotations are extracted, give as a whole very detailed information about what was considered and about the arguments of reasoning in designing the press shoe and the closely connected constructions (Figure 4a), but again the space restrictions of this paper do not allow a more detailed presentation. However, the above quotations give a clue of the dynamics of design thinking and actions in the investigated case.

4.2 Dynamics between strategic planning and design cycles

Figure 5 illustrates the focus areas of the investigated ENP development process. The cyclic nature of the development is evident. The market and competition based demands forced Valmet to make efficient strategic decisions, which resulted in several long-ranging design cycles. The strategic decisions determined the focus areas and individual engineers adjusted their task definition windows accordingly within several different assignments during the two decades long development process.

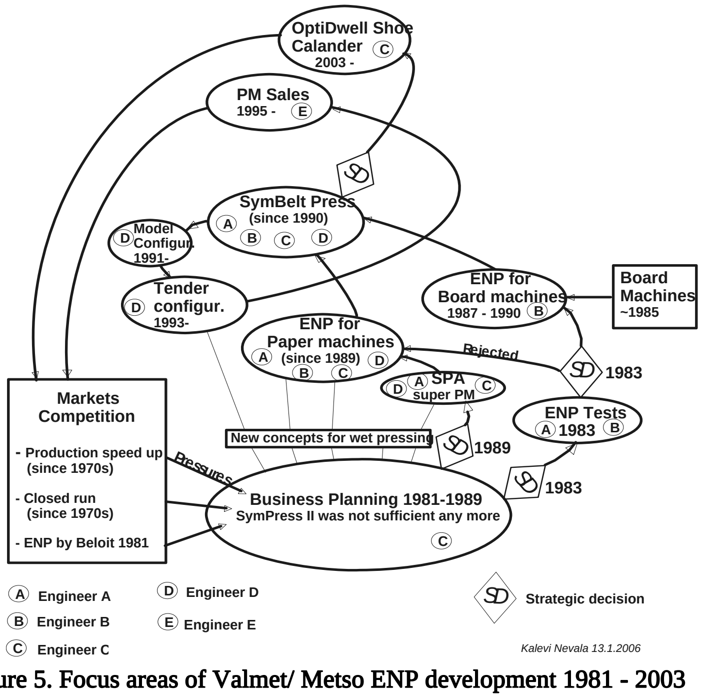

Figure 5. Focus areas of Valmet/ Metso ENP development 1981 - 2003

Our empirical material reveals the importance of strategic planning for successful product development and design engineering. As well, the analysis of the empirical material exposes the difficulties in acquiring sound justification for the decisions and the problems in formulating the objectives so that full commitment of all parties and persons is achieved.

5. Discussion

Content-based analysis of design engineering processes is a resourceful new approach for design research. First of all it offers a possibility to objectively investigate the information contents of the thought processes and other design and interactional activities of the participating engineers. In design engineering the conceptual networks are content-dependent in such a way that the domain-specific functional rules can not be reached by generalized design methods on an abstract level. Content-based analysis can provide scientific data for refining the design methods to fit more closely to the real-life design engineering activities. It is important to search for the content-based logic of thoughts in order to understand how design engineering thinking proceeds and reaches its goals. Our findings suggest that the thinking process of an individual engineer is guided and focused by the functional logic of the task environment and organizational culture. Approaching the total process through the involved individual's mental actions will make a positive contribution to the traditional design science methodologies, towards organizational research and in exploring the true nature of engineering creativity.

As an example of our interpretations of the empirical results we have presented in this paper some aspects of a new notion of task definition window. This new notion is a simple depiction of the conceptual structures of the subjective comprehension about the task situation by the designing engineer. In addition to its worth as a tool in design engineering research, it can also be used as a tool in design practice; the window, its frames and the contents of the view can be easily visualized on paper. Compared with the traditional task definition methods, e.g. the requirements list, etc., the conception of task definition window is more flexible.

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