Adapting the ADS for High Volume Manufacturing

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Abstract. Cognitive Work Analysis (CWA) is a methodology for analysing complex socio-technical systems. It aims to structure system information in a manner that is meaningful for human control and interaction. The Abstraction Decomposition Space (ADS) in an important tool used during the first phase of CWA to describe the work domain. In this paper we create an ADS for a Semiconductor Fabrication Plant. This is a High Volume Manufacturing environment and its complexity necessitates a number of adjustments to the original ADS technique. The physical decomposition of the system is de-emphasised and a number of alternative decomposition hierarchies are used instead. The analysis aims to produce artifacts that aid in the design of decision support systems. These artifacts not only help to assess the information needs of workers, but also structure the work domain in a manner that will inform display design.

1 Introduction

The correct visual representation of data has been shown to improve user performance and reduce human error in a range of domains [1] and many guidelines exist for the correct visual encoding of quantitative data [2]. Advances in sensor and communications technology means that more data is now being generated than ever before. Automated control systems are frequently used to process this data but human operators are often relied on to step in and assume system control if required. In these cases operators must examine data to evaluate the system state and make decisions. The complexity of these domains means that the challenge is not only how to encode the data visually, but also how to decide what data is required for the tasks at hand and how to navigate through the information space. These complex socio-technical systems, generally involve: large problem spaces, multiple users, conflicting constraints, dynamic data, coupled components and unanticipated events. These attributes make it difficult to apply a purely task-oriented analysis approach when designing user interfaces. Cognitive Work Analysis (CWA) [3] is an alternative approach that attempts to structure system information in a manner that is meaningful for human control and interaction. It produces a number of design artifacts that can inform a UI designer about both the system and the user's information requirements.

2 The Abstraction-Decomposition Space

CWA structures system information using means-ends relationships across multiple levels of abstraction. The aim is to support reasoning about a system rather than providing a set path of interaction towards a predefined goal. The Abstraction Decompo-

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sition Space (ADS) is a tool used in CWA to analyse the work domain. The ADS combines two views of a system, a functional means-end hierarchy, ranging from high-level functional purpose to low-level physical form, and a physical decomposition hierarchy, ranging from overall system to individual components. These hierarchies are placed orthogonally in a matrix, essentially mapping function to form at different levels of granularity. Each cell in the resulting matrix describes the entire system at a different level of abstraction. This tool allows us to chart the information requirements of a user at various levels of abstraction during a problem solving task. The ADS has been frequently applied to the design of process control systems in microworld examples. Here we attempt to use it to generate an information navigation and monitoring system for a large and complex domain.

3 Applying the ADS to High Volume Manufacturing

Modern High Volume Manufacturing (HVM) environments are examples of extremely complex socio-technical systems. They combine sophisticated factory automation with the changing demands of dynamic markets. A common constraint across HVM is the conflicting goals of achieving high volumes of production while ensuring that machinery continues to operate within acceptable control limits. High production volumes place machinery under stress, requiring them to receive more maintenance and repair. Repair causes more downtime leading to lower levels of production. This conflict is resolved by humans who must reconcile manufacturing-focused and engineering-focused priorities. A visualisation that could present system state information from both perspectives would benefit users trying to deal with such conflicts. We attempt to construct an ADS for a HVM environment to structure system information in a way that can inform our visualisation design.

Our study focuses on a Semiconductor Fabrication Plant (Fab), involving hundreds of machines (described as tools) and a highly complex process-flow. The overall *process* is divided into a number of *segments*. Segments consist of a number of functional *operations* that build components of the semiconductor. These operations may be repeated with slight variations in different segments, introducing circulation and reentries into the process-flow. Operations are carried out on specific *tools* which are categorised according to specific functional activities. Multiple tools carrying out the same operation are gathered together into a *toolset*. Groups of toolsets that carry out the same general function form a *functional area*. This complex relationship between process-flow and functional areas is shown in fig.1a.

Two basic structures are evident. A Process hierarchy organises the system into different levels of granularity based on position in the process-flow. This equates to the manufacturing view mentioned earlier giving a horizontal view across the process-flow. A Functional hierarchy structures the system in terms of functional areas. It equates to an engineering view giving a vertical view into areas, toolsets and tools.

4 Adaptation of the ADS

The ADS combines a functional abstraction hierarchy with a physical decomposition, but in this case the physical decomposition has limited use. While physical tools

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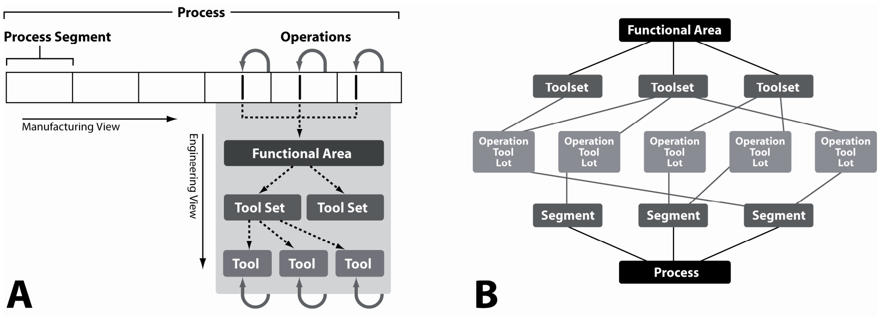

Fig. 1. A) Process-Flow & Functional Area Structures B) Abstraction Lattice

Decomposition →

Abstraction	Process	Segment	Operation
Functional Purpose	Efficient Product Manufacturing		
Abstract Function	Move Product through Process	Advance wafer production	
Generalised Function		Carry out Operations	Carry out an operation
Physical Function			Lot/Tool States (Production)
Physical Form			Wafer in Tool

Abstraction	Func Areas	Toolsets	Tool
Functional Purpose	Maximise Tool Availablility		
Abstract Function		Max. Uptime Min. Downtime	
Generalised Function		Toolset Health Toolset Availability	Carry out PM's Find Faults Fast
Physical Function			Tool States (Health)
Physical Form			Wafer in Tool

	Process	Segment	Operation
Functional Purpose	Produce a Technology		
Abstract Function	Move Product through Process	Advance wafer production	
Generalised Function		Carry out Operations	Carry out an operation
Physical Function			Lot/Tool States (Production)
Physical Form			Tool, Lot Operation
Physical Function			Tool States (Health)
Generalised Function		Toolset Health Toolset Availability	Carry out PM's Find Faults Fast
Abstract Function		Maximise Uptime Minimise Downtime	
Functional Purpose	Maximise Tool Availablility		
	Func Areas	Toolsets	Tool

Fig. 2. Two ADS's for alternate views & Final ADS

match functional operations at the lowest levels, recirculation in the process-flow means that physical and functional relationships no longer equate at higher levels of abstraction, i.e. segment variables do not equate to toolset variables. Lind [4] points out the limitation of an ADS based on a single physical decomposition noting that a physical component within a functional subsystem may belong to multiple functions at the same time. Multilevel Flow Modelling (MFM) provides a technique for dealing with this by replicating the physical components in multiple subsystems. Our problem is somewhat different. Here the process flow is just too large and too complex. This makes a physical model unfeasible to work with. We propose replacing the physical decomposition within the ADS with one based on functional constraints. However, this system features two conflicting functional constraints at the highest level. These are the manufacturing and engineering views discussed earlier. Both of these are valid system decompositions but their relationship is non-analogous. The question is how can we generate a single model of the system that encompasses both structures?

As a first step, two ADS's (fig.2) were constructed and examined, one for each view. While they are very different at the abstraction level of functional purpose, they share the same properties at the level of physical form. This commonality can act as a

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bridging point between the two views. While a single physical decomposition causes us to think of the ADS as an Abstraction hierarchy, using two conceptual decompositions allows us to think of the ADS in terms of an Abstraction Lattice (fig.1b). An Abstraction Lattice allows us to reason our way down through levels of abstraction in one view and then up through levels of abstraction in an alternative view of the same system. This approach allows us to reflect the Abstraction Hierarchy across the level of physical form joining up the two ADS representations. Our new ADS (fig.2) captures all of the system variables from both view at multiple levels of abstraction.

5 Evaluation & Observations

In order to evaluate our adjustments we mapped a use-case scenario for shutting down an Out-of-Control Tool to our ADS. The mapping revealed a number of interesting observations. Firstly, although the user was operating in the engineering area, information from both sides of the ADS was referred to during the use-case. Secondly, information at different levels of abstraction was combined from different sides of the ADS in order to gain a better understanding of the system state. Thirdly, while causal reasoning enables movement between states of knowledge in either view, this cannot explain movement between abstraction-levels that occurs independently in both views. These observations are particularly interesting for display design as they force us to think about visual representations that can encompass different levels of information abstraction within a display and movement between different displays.

6 Conclusion

While the ADS is a useful tool for structuring system information it has difficulty dealing with the Fab environment. Conflict at the level of functional purpose and circulation in the process-flow makes physical/functional relationships problematic at higher levels of abstraction. MFM attempts to deal with this problem and has been successfully applied to plant process control. However the scale and complexity of our domain encourages us to move away from physical decompositions altogether. Our approach prioritises functional constraints over physical ones. By combining functional decompositions of the system it becomes possible to structure information in a manner that is meaningful to users. This modified ADS allows us to chart users information needs when interacting with the system. While a preliminary use-case mapping has been completed, more are being carried out to further test the ADS. This is being used as part of an approach to the analysis and design of displays for a HVM environment.

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