Designing Usable Decision Support Systems for HVM

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Abstract

In High Volume Manufacturing (HVM), system control is shared between automation and human workers. The social organisation of workers plays an important role in supporting human decisions. Advances in the application of automation to a system, may change the social organisation associated with its operation. It establishes new work roles with broader information demands that require advanced Decision Support Systems (DSS). Visualisation tools have been shown to improve decision-making in many situations. While guidelines exist for the visual representation of quantitative data, no methodology exists for displaying complex information structures. We apply Cognitive Work Analysis (CWA) to a semiconductor HVM plant to derive a model of its information structures. This is a first step towards the creation of an interactive visual DSS. A number of modifications to CWA techniques are made to accommodate the complexity of HVM.

1. Introduction

While the automation of physical processes allowed the initial development of High Volume Manufacturing (HVM), the automation of control systems has been fundamental to its growth and development. Advanced Process Control (APC) and Manufacturing Execution Systems (MES) automate labour intensive monitoring and low-level decision making. While these systems are better for handling the masses of data involved in HVM, not all decisions can be automated. The dynamics of manufacturing involves changing demands and unpredictable equipment faults. This dynamism often increases the complexity of problems beyond what is computationally tractable.

Human agents are an important part of any HVM process as they introduce adaptability and flexibility into the system. Humans build up heuristics and patterns of activity from experience with the system. They combine this knowledge with relevant system-state data to make informed decisions. To accomplish this, data is accessed by means of Decision Support Systems (DSS). These are computer based applications and reporting tools accessed through mobile or fixed terminals. In large complex HVM humans work at various management levels and in specialist areas, requiring different views of the systems. Workers form a social organisational structure whose combined efforts allow the factory to operate.

Human-factors is the study of psychophysical, psychological, and physiological variables which affect human performance in an operational system. Automation has lessened the impact of physiological limitations in modern manufacturing. However, increased complexity and the removal of direct physical control pose major psychological challenges to humans. Issues include the learning of interface elements, understanding the system and communication through mediated control. A major challenge in HVM is how to present system state information to human agents in a way that is relevant to their work roles. Only through understanding the perceptual and cognitive limitations of the human mind can we begin to design systems that can achieve this.

Semiconductor manufacturing is a highly automated HVM domain. Current trends towards the production of larger silicon wafers have increased its automation requirements and this in turn is changing the operational model of the Semiconductor Fabrication Plant (Fab). One concept associated with the future development of Fabs is that of a control centre where Area Operators remotely monitor and react to the system state. This reflects not only a change in job design, but a change in the overall social organisation of the system. These new operators have very different information needs to the original Machine Operators and require an advanced DSS to compensate for the changes in social structure. This paper outlines an approach to structuring information needs in HVM. These structures are a vital first step in designing interactive visual Decision Support Systems.

2. Characteristics of the HVM Environment

Modern HVM facilities belong to a class of system described by Vicente [12] as Complex Sociotechnical systems. These generally involve large problem spaces, multiple users, conflicting constraints, dynamic data,

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coupled components and unanticipated events. 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. While many of the low-level decisions involved in the process can be handled by automated control systems, this higher level conflict is generally resolved by humans who must reconcile manufacturing and engineering priorities.

2.1. Semiconductor Manufacturing Process

Semiconductor manufacturing is an example of HVM consisting of complex process flows, hundreds of tools and thousands of workers. The overall *process* is divided into a number of *segments*. Segments consist of a number of functional *operations* that build components of the semiconductor device. These operations may be repeated with slight variations in different segments, introducing re-entries into the process-flow. Operations are carried out on specific *tools* which are categorised according to their functional activities. Multiple similar tools carrying out the same operations are gathered together into a *toolset*. Groups of toolsets that carry out the same general function form a *functional area*. The system produces multiple *products* which have slight variations in their process-flows. Clients place *orders* which are ultimately run in the Fab as physical *lots*. Lots move through the process on an automated material handling system. The processing of product is carried out in a clean-room environment.

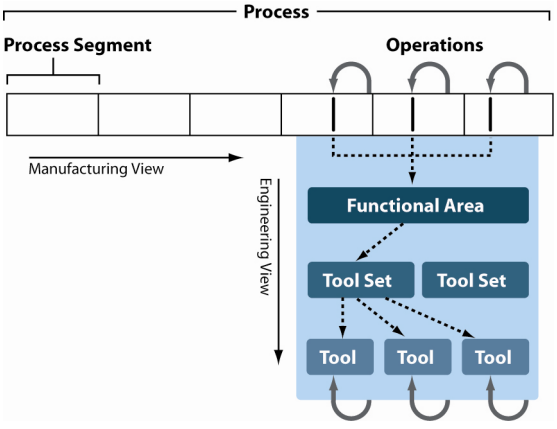


Figure 1. Process Flow & Functional Areas.

The complex relationship between process-flow and functional areas is shown in fig 1. Two basic structures are evident. A Process hierarchy allows us to organise the system into different levels of granularity according to position in the process-flow. This equates to the manufacturing focussed view mentioned earlier and facilitates a horizontal view across the process-flow. A Functional hierarchy allows us to think about the system in terms of functional areas. It equates to an engineering focussed view and gives a vertical view down into areas, toolsets and tools.

2.2. Social Organisation

The organisation of workers plays an important role in complex sociotechnical systems. Hutchins [5] points out a number of advantages that strict hierarchal social-organisation offer including: distributed responsibility, error-reduction, safe participatory learning, task-sharing and parallel action. This approach encourages information hiding allowing high-level managers to focus on higher level issues without getting overloaded by details. The Fab maintains a strict organisational structure based on the two conflicting system constraints outlined above. Figure two illustrates this structure along with its associated information requirements. Within the manufacturing view, a Machine Operator (M.O.) ensures that an operation is carried out by placing product into the tool. They are also responsible for organising and building lot queues at the tool. A Manufacturing Engineer (M.E.) is concerned with the performance of a segment in the process. They look at the Wafer in Process (WIP) levels above and below their segment. A Production Manager (P.M.) is concerned with the overall WIP and the movement of product between segments. From the engineering side an M.O. operates an individual tool and is aware of its performance levels. An Equipment Engineer (E.E.) repairs and maintains tools within toolsets. A Process Engineer (P.E.) is concerned with the toolsets health and the overall tool availability in a functional area. Engineers usually specialize within a specific functional area but their information requirements often go beyond this.

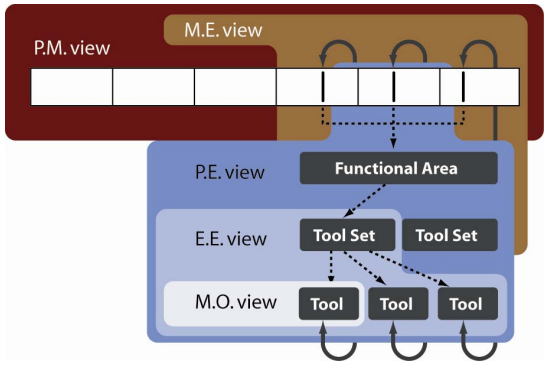


Figure 2. Social Organisation

2.3. Decision Making

Automated systems handle many of the low-level decisions involved in HVM. APC ensures that a manufacturing plant maintains high levels of system control (or health). It analyses real-time data from tools to insure that they are operating within strict control limits and can automatically shut down faulty tools. An MES tracks product progress through the plant. It

measures WIP in terms of product volume and position in the process and monitors the availability of equipment. System data is available to workers in the clean-room through a range of applications that make up the Shop Floor Control System. This data guides their actions informing them about product/tool assignation and tool health. It also allows them to carry out certain operational tasks such as building queues, changing recipes and taking equipment offline.

Higher-level decision making occurs during meetings where information at multiple levels of abstraction is more freely accessible. Shift pass-downs are held at the beginning of each shift to inform machine operators about the system state within their area. Morning Operations are attended daily by Equipment Engineers, Process Engineers and Manufacturing Engineers to discuss issues and plans of action for the day. Weekly Operations are attended by Process Managers and Manufacturing Supervisors to discuss WIP rates and major changes within the process-flow.

These meetings have different information requirements that go beyond the low-level data accessed by Machine Operators. These requirements are handled in two distinct but complementary ways. Firstly, custom reports are generated at the correct level of detail to support the decisions being made. These are a mix of static and dynamic data represented in text, graphic and spreadsheets format that give a specific view of the system. Secondly, workers from different areas or levels act as gateways into further details. They can verbally provide the detail behind the report metrics and explain why certain actions have been taken.

While it is possible to describe the applications associated with the shop floor control system as DSS's for low-level decisions we can see that higher-level decisions are far more complex. The DSS for high-level decisions is neither the shop floor control system, nor is it the custom reports. It is a process that is distributed between the automated control systems, reporting tools and a complex social organisation.

3. Human Factors in Command Centres

As stated, the trend towards producing larger silicon wafers has increased the need for automation in the Fab. The weight increase associated with larger wafers restricts the manual handling of product for ergonomic reasons. As a result Automated Material Handling Systems (AMHS) are becoming more pervasive allowing product to be automatically loaded into tools. They are also becoming more technically sophisticated, handling queue building with greater efficiency than human operators. These two factors contribute strongly to the concept of central command centres. Without the physical task of machine loading, machine operators are no longer tied to a tools physical location. The automation of queue building removes a recurring, high-workload task from the operator's role reducing the amount of time an operator needs to spend at an individual tool. This implies a number of changes in the role of an operator in a central command centre. Firstly they will probably be responsible for a larger number of tools and will need to access these tools through a single interface; secondly the interface should facilitate the operator in controlling and monitoring individual tools, comparing multiple tools performances and give them the ability to associate this information with overall performance goals. We describe this new work role as an Area Operator.

3.1. Automation changes Work Roles

The role of an Area Operator (A.O.) is very different to the original machine operator and their skills-level and information requirements differ accordingly.

Firstly, the new A.O.'s require a much more extensive knowledge base than the existing machine operators. It has been noted that the introduction of automated technologies requires a corresponding increase in the skills-level of the operators [1]. Bruce Sohn, Intel's Fab 11X factory manager recognised this in an interview with Micro Magazine "In the olden days, an individual technician might have been an operator on two or four tools; five tools maybe if he or she were especially good. In the central command centre, we may have one person managing dozens and dozens of tools of different varieties". [4]

Secondly, there is a change in terms of responsibility. Previously, responsibility for the health of toolsets and functional areas would be distributed amongst a network of specialists at different management levels. This network has a number of built-in safety mechanisms including redundant knowledge, cross-checking and micro-management. The new A.O. must assume responsibility for a number of these positions.

Thirdly, Brann [3] demonstrates that automated control systems often change job roles from operation and control to management-by-exception. While some operational tasks still remain for the A.O., many of the monitoring activities can be handled by the system. Current machine operators' continuous interaction with tools means that they maintain a high level of tool state awareness. A.O.'s will be much more reliant on automated control systems for revealing important, temporal, system-state information. They will generally only assume temporal control of the system where conflicts or major faults occur. This means that an A.O. will usually be called upon when the system is already unstable, so an immediate interpretation of the system state is essential to allow for diagnosis and quick recovery.

3.2. New Information Requirements

These changes in work role have a massive effect on the cognitive workload of the new Area Operators. The

new role spans a wider area of the systems social organisation and as such deals with a wider range of issues. A.O.'s must be able to understand a range of different variables for a variety of tools. They must be able to prioritise issues across different tools and move quickly between high-level metrics relating to toolsets and lower-level tool-specific data. In short their knowledge of the system and the system state needs to be broader and better supported. In order to allow this, control interfaces must be designed to make the system inspectable, predictable, repairable, maintainable and extensible [3].

The effectiveness of the original reporting tools as a method for conveying system state information is reduced. Reports were targeted at specific levels of management, as the new role spans multiple management levels, multiple reports are required. Previously, the network of workers could expand on information about their areas providing lower level data, the A.O. must be able to source this information independently. The current reports are multi-page documents. A report that features all of the relevant information at multiple levels of abstraction would be very large and require a huge amount of searching to get a full understanding of the system state. This goes against the A.O.'s need to instantly understand the system state when dealing with fault scenarios. The control interface must allow quick and easy navigation around system information.

3.3. Visual Representations

Area Operators will need a way of quickly interpreting masses of data about the system to gain an understanding of the system state. Visual representations of data have been shown to be effective in displaying large scale data sets [2, 11]. What's more, the correct visual representation of data has been shown to improve user performance and reduce human error in control environments [13]. Psychological research provides us with empirical evidence supporting the use of visual representation in problem solving activity [6, 14, 15], however much of this research has been carried out in relation to small controlled problem spaces. While guidelines exist for the visual representations of quantitative data [11], no methodology exists that informs designers how to display complex information structures. This makes it difficult for designers to choose between alternative information displays when creating interactive visualisation systems.

Visualisation research to date has had a strong focus on multivariate displays of large data sets for data analysis. The system we have been describing is very different, involving thousands of variables, from multiple heterogeneous data sources and multiple levels of abstraction. Rather than displaying all of the data and making the user search for information, we need to structure the data in a way that matches the overall system and allows the user to quickly find the information they need. Only when the data is correctly structured can we begin to create our visual representations of the information.

4. Cognitive Engineering

Cognitive engineering is the analysis, modelling, design and evaluation of effective human integration in complex sociotechnical systems. A number of different methodologies for structuring information requirements in interactive systems have been proposed.

4.1. Different Approaches to Cognitive Engineering

A normative approach uses the "One Best Way" principle and focuses on manual efficiency. Hierarchical Task Analysis (HTA) [10] is a normative analysis methodology that has proved excellent for mapping information requirements in stable, closed-system applications. HTA defines a work scenario and calculates the most efficient set of actions for carrying it out. This makes it unsuitable for HVM applications where hundred of unique roles and unpredictable system behaviour make it impossible to define all scenarios.

A descriptive approach uses the principles of user-centred design to analyse systems. User analysis observes current work patterns to define the information requirements and usage models of new systems. The number of unique user roles involved in HVM again makes this approach unsuitable.

The formative approach to analysis is radically different. Here the goal is to describe the system in a manner that allows users to reason about its functionality and performance. Rather than describing set tasks, it seeks to describe the system and its state, allowing users to control aspects of the system according to their tasks. This gives the system flexibility when dealing with unpredictable faults by allowing the user to close the gap in the control process. It also encourages system state awareness. In the remainder of this paper we carry out a formative analysis of the Fab to reveal an information structure that can guide of our display designs.

4.2. Cognitive Work Analysis

Cognitive Work Analysis [12] is a formative approach to analysing complex sociotechnical systems. It describes systems at different levels of granularity based on physical and functional constraints. This accommodates different worker roles in the same system and can deal with non-normative work scenarios.

The Abstraction Decomposition Space (ADS) is a tool for carrying out Work Domain Analysis, the first stage of CWA. It creates a description of the system by combining a decomposition hierarchy with an abstraction hierarchy. A decomposition or part-whole hierarchy splits a system into its subsystems and then subsystems into components. It reduces complexity by

dividing a system into smaller functional units. An abstraction hierarchy is a description of a system in terms of functionality, from high-level goals down to the physical description of individual components that carry out basic physical tasks. Rasmussen [10] proposes five divisions; Functional Purpose, Abstract Function, General function, Physical function and Physical form. The ADS places these hierarchies orthogonally against each other on a two dimensional plain. This provides us with a multilevel view of the system where each level describes the entire system at a different granularity.

The Decision Ladder (see fig 6) is a tool for carrying out Control Task Analysis, the second stage of CWA. It seeks to describe the information requirements and cognitive activities carried out by a user during interaction with a system. The decision ladder was developed in relation to the SRK taxonomy of control based reasoning [8]. SRK stands for three levels of cognitive control: Skills, Rules and Knowledge based control. As problems reach higher levels of complexity they move from skills based towards knowledge based control and the information requirements move from raw data to high-level metrics and structural relationships. Based on this theory the decision ladder proposes two steps involved in cognitive activity: States of Knowledge and Data Processing Activities. These steps are interspersed throughout the process of problem solving. Causal reasoning can be seen as a linear progression up through the Abstraction Hierarchy using data processing activities to move from lower to higher states of knowledge about the system. Thus, higher levels of abstraction in the Abstraction Hierarchy correspond to higher level states of knowledge required in the decision ladder for goal formulation.

4.3. Advantages of CWA for Complex systems

CWA has a number of advantages over other analysis methods. Firstly, as the ADS is based on system constraints it provides a description of the system that is more accurate than one based on an individual users experience. Secondly, the decision ladder makes no reference to actors it simply states the information required to move between states of knowledge about the system. This means that the action can be carried out by a human actor, an automated controller or a combination of both. Thirdly, we are able to chart the information used in the decision ladder to the ADS thus providing us with a map of a users information requirements for carrying out an action. Finally the ADS can be used to map the social organisation of the system clearly marking the boundaries of information requirements for different human agents in the system.

5. Applying CWA to a HVM Environment

While CWA was designed for complex sociotechnical systems, its application in the original framework focussed on a representative microworld [12]. The complexity of the Fab poses a number of issues for CWA and for the construction of an ADS in particular. The orthogonal placing of abstraction and decomposition hierarchies is a relatively straightforward affair when dealing with microworlds. In many cases a functional disassembly of the system will map directly onto a physical disassembly, with subsystems directly responsible for carrying out generalised functions of the overall system. This is not the case with a Fab.

5.1. Complexity demands Multiple Hierarchies

Instead of a single decomposition hierarchy our initial analysis defined four decomposition hierarchies that could be used to accurately describe the system (see table 1). Some coupling exists between the physical and functional hierarchies and also between the process and product hierarchies, but the relationship between the functional areas and the process is highly complex and non-orthogonal. For this reason they cannot be combined into a single hierarchy. The question then arises which of these decompositions should be used to build our ADS?

Physical	Functional	Process	Product
FAB	FAB	FAB	FAB
Bays & Chases	Functional Area	Process	Product
Toolsets & Workers	Toolset	Segment	Order
Tool	Tool	Operation	Lot

Table 1. Multiple Hierarchies of the Fab

In order to note the extent at which these decompositions could capture the system we created two ADS's (fig 3), one based on process flow and the other on a functional understanding of the system.

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

Figure 3. Process & Functional ADS's

5.2. Abstraction Lattice

The two ADS's can be thought of as the vertical (up and down in the Functional Areas decomposition hierarchy) and horizontal (along the process production line) views of the system referred to earlier. Neither gives an entire view of the system but they cannot be fully integrated, as they are not analogous. These representations meet at the lowest abstraction level of Physical Form, where a lot enters a tool for a specific operation.

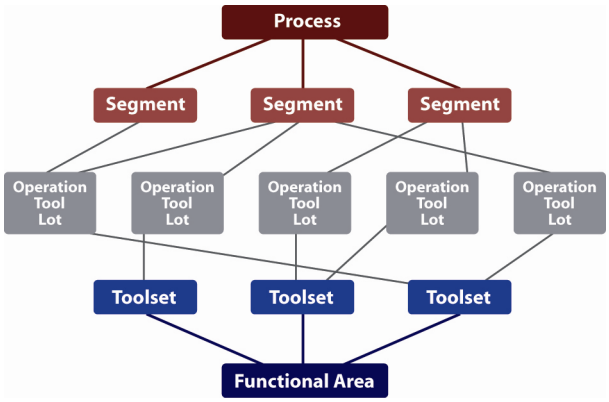


Figure 4. Abstraction Lattice

	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

Figure 5. New ADS

The purpose of the ADS is to describe a system in a manner that is meaningful to the user and hence useful to the designer. Each section in the space is meant to encapsulate the entire system at different levels of abstraction. A decision-ladder can be mapped directly onto an ADS specifying both the information and the level of granularity required at specific point in time to allow the user to move to the next state of knowledge. Thus, the mapping process can inform a designer what variables must be present on screen to support this movement. By carrying out a number of mappings the designer can identify the common variables that need to be explicitly represented, why the user requires them and how a user can reach them.

While the two ADS's we have designed can satisfy either a vertical or horizontal view, many of the human decisions involve information from both views therefore we need some way to join the two ADS's. The Abstraction Lattice (fig 4) allows us to construct a single model for viewing the constraints of a system with non-orthogonal hierarchies. Essentially the Lattice reflects the Abstraction Hierarchy against two decomposition hierarchies that share components at the level of Physical Class. This approach joins the two views of the system and should allow a user to logically navigate between views. Based on the Abstraction Lattice a new ADS with multiple hierarchies has been created (fig 5) on which we can map the decision ladders of different workers who require different or multiple views of the system.

6. Evaluation of ADS

As a structural map of the systems information the ADS allows us to chart the information requirements of different workers. How this can inform the design of visual displays? The microworld case-studies mentioned earlier found it useful to encode the ADS in the visual display of control systems using visual chunking. This approach does not suit displays for a fab, as the vast scale of the system makes it unfeasible to display all of the components in a single view. Currently the social organisation makes it unnecessary to view the entire system, but new A.O.'s will need to be able to view different levels of detail. The hierarchies used in the ADS allow us to structure the granularity of the system. By studying user's movement around the information structure when carrying out tasks, we can identify what transitions between views are required and what contextual information also needs to be supplied.

6.1. Decision Support Analysis

We create a use case for a task that a new Area Operator (A.O.) may have to carry out. The A.O. will be responsible for ensuring that a range of tools are processing product efficiently and maintaining suitable levels of health. Below we describe a situation where a tool is trending towards an Out Of Control (OOC) state. The use case lists the decisions and actions that the A.O. must carry out before reaching a stable system state. By mapping the use case to a decision ladder (fig 6) and the ADS (fig 7) we can chart the user's navigation through the information space.

6.2. Use Case

|**1**| The system indicates that a tool is trending towards an OOC state. |**2**| The Decision Ladder moves to a state of Alert, informing the A.O. that action must be taken. |**3**| The A.O. needs to observe what has caused the alarm. This involves locating the toolset, the individual tool and the lot being processed |**4**| The A.O. now has a set of observations identifying the cause of the alert. |**5**| The user needs to identify the system state at the correct level of granularity, by identifying |**5a**| toolset |**5b**| product approaching toolset |**5c**| toolset health. |**6**| A.O. now understands the current system state in terms of product distribution and system health. |**7**| They can now interpret the alarm in terms of the overall system. |**8**| Interpretation is based on the effect any action will have on the functional purpose of the system, maintaining A) high volumes of production and B) high levels of tool health. The tool is unhealthy and should, according to criteria B, be shut down, but the consequences of this must be judged against criteria A. The user must judge the volume of product approaching against the toolset health to see whether demand can be satisfied. |**9**| The Goal State will either have the tool on or off depending on the interpretation. |**10a**| If toolset is healthy and the approaching volume is low the tool can be taken off-line. |**10b**| If health is low and approaching volume is high, tool reconfiguration may have to occur. |**10c**| If health is low and approaching volume is low, the tool is allowed to process the current product before shutting it down. For the sake of clarity we will pursue the first option.|**11**| Having taken the decision to shut down the tool we now formulate the task. |**12**| This may involve assigning tools to other products, initiating shut down and placing the tool on a repair list. |**13**| These actions are then executed either by the user or by the system.

6.3. Mapping the Use Case

This mapping reveals a number of interesting facts about the A.O.'s information requirements. Firstly, although the task is initially concerned with tool health and the functional view, information is also required from the process view during decision making. Secondly, as the operator is responsible for a group of tools it is necessary to understand the overall health of toolsets before carrying out actions on a specific tool. This equates to movement up through the abstraction hierarchy. Thirdly, movement up and down the decision ladder does not always involve the same movement on the abstraction hierarchies of both views. During Task Formulation (step 12) the user referred to information from three different points in the ADS. This implies that simple movement between levels of granularity may not be sufficient in our visual display and that contextual information will need to be accessible to the user. Despite the Fab's complexity, our ADS supports all of the required data at the various levels of abstraction required to complete the decision making process.

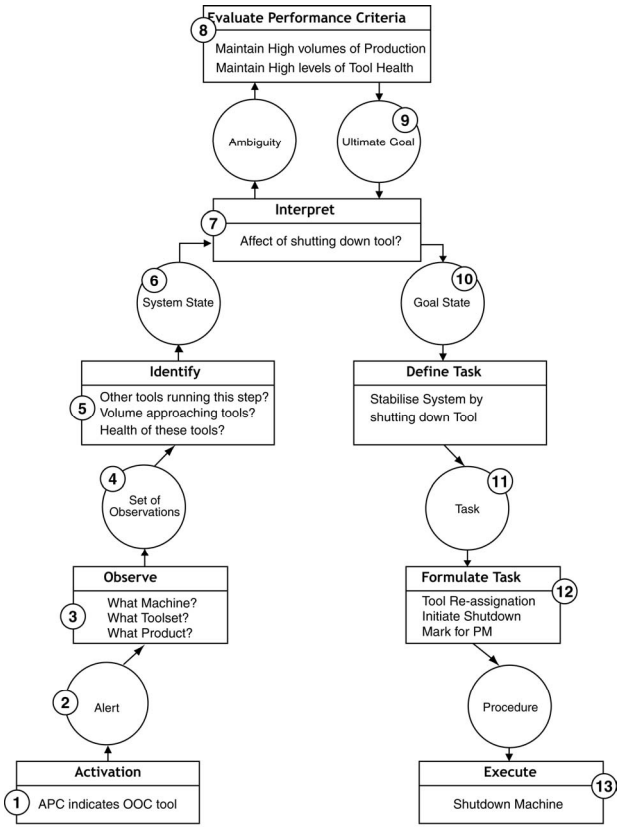


Figure 6. Decision Ladder

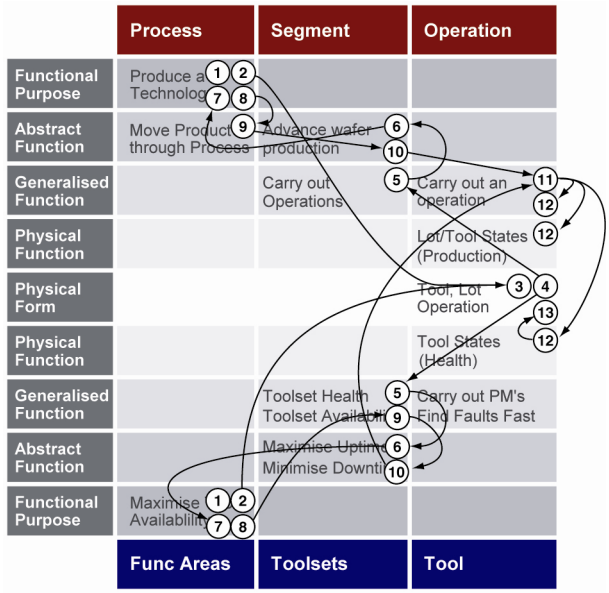


Figure 7. Use Case mapped to ADS

7. Informing Visual Design

As mentioned before, microworld analyses have chosen to encode the entire ADS into the final visual interface. They do this by visually encoding raw data variables and then grouping them in a manner that

matches the decomposition hierarchy. This technique uses gestalt principles of perception to build visual structures that represent information structures. The sophistication of the human visual system allows users to see the high-level functional relationship between subsystems, while also allowing them to visually zoom in and focus on details in areas of interest.

The Fab is a larger, more complex environment. The sheer number of variables involved poses a serious issue for visual perception. With so many variables visual structure can quickly degrade into visual noise. Rather than relying on the visual system to carry out zooming we can provide a zooming interface that allows us to quickly navigate around our information structure. However, as our use case reveals, there is a further issue regarding dual hierarchies. Information may be required from both hierarchies to support decisions. These factors highlight some important issues for the visual encoding of data. Firstly, the visual variables [2] used to express data must be consistent across different levels of abstraction. For example, tonal value, if used to express the health level of a tool, must also be used to express health levels of toolsets and functional areas. Secondly, the visual variables that represent a component must be selectable. This is required to allow access to data contained at a finer level of detail and for the provision of contextual links to other areas of the information structure.

8. Conclusions

In this paper we examined human factors issues in HVM central command centres. We have shown that social organisation plays an important role for decision making in the semiconductor HVM environment. Advanced developments in automation will change the social organization of the Fab and increase the information requirements of workers located in command centres. We have discussed the need for a more dynamic DSS and how interactive visualisation may be the best method of achieving this. We note the lack of a methodology for achieving this.

CWA is a useful method of structuring data and provides us with an important first step in the design of visual displays for complex sociotechnical systems. The complexity of the fab, with its multiple, non-analogous decomposition hierarchies, requires us to adjust the ADS tool. We propose the development of an ADS using multiple hierarchies as a useful interpretation of this HVM system.

The new ADS allows us to map the workers information requirements when carrying out tasks. This mapping reveals the path a user takes through the information structure, allowing us to see what information needs to be present in a visual display at various stages in the decision making process. It also informs the designer about the need to visually encode the hierarchies involved. Suggested strategies include a combination of interactive zooming and visual variables that support selection.

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