Geared Decisions:
Experimenting with Decision Support Visualizations

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Abstract: A Human-Machine Interface (HMI) is where people and machines (most often within an industrial context) interact during a given task. The goal of this interaction is for the user to operate and control the machine in an effective manner, while receiving from it helpful and timely feedback. In some contexts, an HMI may also function as decision support system (DSS), or have DSS components, aiding users in making effective decisions about some aspect of the industrial operation.

In this paper, we discuss the iterative design of an HMI–DSS based on a mathematical model for an ice-cream manufacturing operation. We chose ice-cream manufacturing as a working example because it is a multi-modal system, containing sufficient process complexity to be generalizable to many other kinds of industrial operations. One of our design goals is to provide users with a display that includes both quantitative and qualitative information types related to the situation requiring a decision. In addition, we aim to provide users with an exploratory environment that enables them to experiment with decision alternatives – their past and potential consequences – prior to actually carrying out the decision.

Key words: Decision Support, Interface Design, Manufacturing.

1. Introduction

Computer-based decision support systems (DSSs) are defined as systems that have been designed to support and improve human decision making. Another popular definition given by Sprague and Carlson [1] identifies a DSS as an interactive system that assists decision makers to use appropriate data and models to solve semi-structured and unstructured organizational problems. There is some debate on the nature of a more specific definition. According to Keen [2], some researchers define a DSS simply as an interactive system for use by managers; some focus on the DSS as a support in the decision process; while others focus on DSSs as a way to access analytic models.

The DSS contemporary professional practice includes personal decision support systems (PDSSs), group support systems, executive information systems, online analytical processing systems, data warehousing, and business intelligence [3]. DSSs exist in numerous domains; notable work has taken place in business, medicine, defense, manufacturing, transportation, forestry, and law. Our focus, for this project, has been in decision support within an industrial/manufacturing context. In manufacturing, a DSS may take place within a stand-alone system (the mathematical models calculated in an Excel or Excel-type application); or as part of a larger system category called the Human-Machine Interface (HMI).

The work described in this paper is part of a larger research project, the goal of which is to develop a framework for plant-wide decision making. One of the critical components of this project is the development of novel approaches to interface design. Our design starting points are HMI designs for industrial plant operations; and graphical outputs for decision support. For the purpose of this paper, we will use the terms HMI–DSS to identify our work in the design of human-machine interfaces that support decision making, within the context of industrial plant operations.

Many HMI designs haven't seen significant advancement – change or improvement – in the past twenty years [4]. Similar is true for the output associated with decision support systems – it is generally displayed to the decision-maker using graphics whose origins date back more than three decades and do not effectively present critical sensitivity information to the user. Where development has taken place – except for few notable exceptions – it has been in the form of varied design configurations, bright touch screen displays, and BASIC-like object-based programming language that enable "quick and easy custom application development and integration" [5]. These features have a tendency to work against, instead of supporting, the user [4]. In contrast, a well designed HMI should provide clear and effective communication, empowering users to be more effective at doing their jobs – helping to manage critical information, effectively complete work tasks, and make informed, timely decisions [6].

In consultation with a team representing an Alberta-based manufacturer and a team from the Chemical and Mechanical Engineering Department at the University of Alberta, we are iteratively designing an experimental alternative to a more typical HMI–DSS. The broad goal of our project is to help future users make effective manufacturing decisions. More specifically, we are interested in contributing to the existing discourse about what design strategies help to make an effective HMI–DSS, while including not just the quantitative – but also the qualitative – experiences of the decision makers within our design. Our goals for this project is to design a HMI–DSS that provides decision-makers with all of the information they need to make effective choices, including identification of optimal operating variable values and the sensitivity of these optimal values with respect to assumed process parameters.

In this paper, we provide some background to human-machine interface and decision support system design, and then describe our recent concepts for a new series of HMI–DSS visualizations, the goal of which is to consider both the rational and the emotional aspects of human decision making.

2. Background and Relevant Literature

2.1. A brief history of HMI design and DSS

Industrial plant operations have an over sixty-year history of HMI design, beginning with the Control Panel. In the 1930s, and up until the 1970s, most manufacturing plants had a small room where most of the control instruments were housed. Instruments were logically grouped, alarms carefully selected and placed together in separate lightbox panels and, sometimes, a pictorial representation of the plant was used behind the appropriate instruments [4]. In the 1970s, Distributed Control Systems (DCS) began to replace the Control Panel. Physical instruments were replaced with software displays, and signals began to be monitored by computers. Unfortunately, the graphical representation components of the DCS that were developed at that time have seen only marginal advancement since. Similar is true for the output associated with decision support systems, in particular within an industrial/manufacturing context. The history of decision support can be traced back to work conducted on management information systems (MISs) in the early 1960s [7], theoretical studies of organizational decision making done at the Carnegie Institute of Technology during the late 1950s and early 1960s, and technical work on interactive computer systems, mainly carried out at the Massachusetts Institute of Technology in the 1960s [8]. Early DSSs were interactive IT-based environments for human decision makers – the information system provided assistance to the human dealing with the complex unstructured parts of the problem by automating the structured elements of the decision situation [9]. The purpose of this process was to improve the effectiveness of, not replace, the decision maker. Few MISs achieved any form of success – the systems were large and inflexible and the reports generated for the managers, while extensive, contained very little useful information [10].

During the mid 1970s the concept of DSSs evolved into an area of research; during the 1980s research activity in the area gained intensity. The single user and model-oriented DSS evolved into executive information systems (EISs), group decision support systems (GDSSs), and organizational decision support systems (ODSSs) [11]. By the mid-1990s, researchers were exploring the possibilities for using the World Wide Web and Internet technologies for building and deploying decision support systems, and by the end of the 1990s, several software firms were working on new Web-based analytical applications [11]. In early 2000, Bhargava et al. [12] envisioned going beyond Web-based individual DSSs to a collection of systems from multiple providers sold on a pay-per-use basis via an electronic library. Work continues in this area.

More domain-specific and notable work in DSS design and development has taken place in business, medicine, defense, manufacturing, transportation, forestry, and law [13][14][15]. One such system, PROMIS – The Problem-Oriented Medical Information System – stands as one of the major breakthroughs in interface design for decision support, and included on-demand access to patient, symptom, and laboratory information, as well as epidemiological studies and other research endeavors. PROMIS also allowed for medical and business audits to aid organization and efficiency in the management of common medical and surgical disorders [13]. Advancements have also been made in simulation and visualization of air traffic control [14][15], where effective decision making requires the support of multiple actors with different views on the system and the possible outcomes of the decision process.

Modern DSSs provide business managers with decision support for tasks such as information gathering, model building, sensitivity analysis, collaboration, alternative evaluation, and decision implementation [11]. Within the business domain, decision support falls under the broad category of Business Intelligence (BI). BI is used to gather, store, analyze, and provide access to data, in order to help enterprise users make better business decisions. Within the business domain, DSSs are seen primarily as providing opportunities to improve the effectiveness and productivity of managers and professionals, in order to strengthen the organization and rationalize the decision making process [16]. Successful DSS applications have tackled decision problems in a broad range of managerial and policy environments, at both the operational and strategic levels.

2.2. Designing for 2030

2.2.1 Benefits

Decision support systems come in many shapes and sizes depending on the context of their implementation – the scale and complexity of the domain, organization, and/or the decision making process. One basic example of DSS use would be if an on-line book seller wanted to determine if selling his products internationally would be a wise business decision. A DSS could collect, analyze, and present data from internal and external sources in order to help the seller determine if there is demand for such an expansion and if the company has the ability or potential ability to expand its business. In a more complex example, a DSS could be developed for plant-wide decision-making, with a view of improving knowledge of the global impact of individual decisions. For example, what is the impact on water, gas, and oil consumption if ten more trucks are added to the system?

A well-designed DSS has many potential benefits. For example, it may improve personal and organizational efficiency by expediting problem solving within an organization. A DSS can also facilitate interpersonal communication and promote employee development through training. Through a DSS, organizations may increase their level of control over the decision-making process as well as internal and external accountability via an increase in the amount of evidence in support of a decision and automation of the managerial process. Quicker and smarter decisions may mean a competitive advantage over other companies and an increase in innovation and discovery.

Furthermore, in certain critical instances an HMI–DSS can mean the difference between successful crisis resolution or, and this is the unwelcomed scenario, an industrial disaster. One such example, the largest petrochemical plant disaster in U.S. history that was not due to natural causes, took place at a petrochemical plant in 1989. It cost the company $1.6B. According to the *Abnormal Situation Management Consortium (ASM)*, the cost of lost production due to industrial accidents is at least $10B annually in the U.S; costs of equipment repair, replacement, environmental fines, compensation for human casualties, investigation, and litigation represent another $10B [17]. These monetary costs do not take into account the vast emotional impact such disasters have on industry employees and their families, as well as the communities within which the disaster takes place.

2.2.2 Characteristics

Miner et al. [18] describe a number of general characteristics for an effective decision support system – all with the goal of supporting the user throughout the decision making process:

- Conversational and interactive: users can interact with the system using English-like commands.
- Flexible: users can combine different modules or segments of the system to solve a problem.
- Adaptable: the system is changeable according to the user's needs and capabilities.
- Helpful: the system should be simple and forgiving.
- Quick: the system should be responsive and timely.
- Reliable: the system should be reliable and give correct answers.

In addition, several authors have developed detailed recommendations regarding the characteristics of an effective visual structure for human-computer interfaces, including guidelines on typography sizing and selection, colour/background contrast, graphical treatment, and animation use [4][6]. We agree with these recommendations, in principle. One of the basic requirements for these interfaces is to effectively communicate complex mathematical calculations into forms that are accessible to operators who may not have a background or training in engineering math. In addition, certain decisions must be made using vast amounts of data under intense moments of stress. The use of clear, well-structured visual representations is therefore a priority.

The above-mentioned characteristics of a good HMI–DSS can be said to apply to all interface types. Yu (2004) adds to that list recommending, more specifically, that the visual interface for a DSS should allow users the following actions [16]:

- generate and submit requests for information and decisions;
- browse retrieved information including the computational results of decision models;
- revise inputs and activate “what if” analysis;
- give and receive feedback with respect to system outcomes and performances;
- select and execute applications and functions; and
- login to and logout of the application.

We believe that an effective HMI–DSS will adhere to advanced standards of visual quality, as suggested by Hollified and Few; support users in their work tasks, as suggested by Miner et al. and Yu; and, as suggested by Shen-Hsieh and Schindler [19] accommodate not just the quantitative but the more qualitative data, therefore leveraging human knowledge and experience into the decision-making process.

2.2.3 User types

Once implemented, an HMI–DSS has to meet the needs of different types of users, depending on its intended sector. A system for the military, for example, will be fundamentally different from one designed for business, and the users will vary in terms of their needs, expertise, strategies for knowledge management, and managerial hierarchy. However, most HMI–DSSs will, at minimum, attempt to serve the following four groups of stakeholders:

1. Developer and maintainer: the system has to enable this user to accelerate the development process and streamline the maintenance process.
2. Model builder: the system must provide this user with ways to create manufacturing process models, decision scenario models, and analytic tool models.
3. Operator: the day-to-day operator of the HMI–DSS; this user is provided with tools for manipulating the required data (and, possibly, related machine components) and creating useful outputs.
4. Manager: this user manages others who use the HMI–DSS; s/he may require regular outputs in the form of system reports.

In addition to the stakeholder group use mentioned above, a manufacturing HMI–DSS may be used for training and public relations purposes. Visitors to the manufacturing site may be invited to view selected parts of the system, in which case certain processes and/or decisions may need to become hidden from view.

3. Our interface

Our research in the area of HMI–DSS design builds on our previous work in experimental visualization. It is grounded in areas as diverse as literary historical collection browsing [20], decision support for provincial parks management [21], and knowledge discovery processes for data mining operations [22] follow an iterative design cycle that includes three primary phases: conceptual and theoretical work supported by sketches; prototyping informed by user study; and production and implementation, with further information provided by analysis of logs. The objective of our work on HMI–DSS visualization, more so than our work within other research domains, is not to implement current best practices, but rather to help invent the next generation of best practices. Our goal is to answer the question: what would an effective HMI–DSS look like in 2030?

Since much of the actual data we are dealing with is proprietary to our manufacturing partner, we have chosen an ice-cream manufacturing operation as a working model in place of the real data. Ice-cream manufacturing is an appropriate alternative because it is a multi-modal system that contains sufficient complexity in the processes to be generalized to many other kinds of operations. This project is a continuation and expansion of a previous project entitled “Optimization-based Decision Support for Integrated Mining Operations”, which focused primarily on the visualization of truck allocation problems and analysis of vector optimization problems [23].

In 2008 we ran a study on a previous iteration of our interface [24], which identified several types of information that our design was not supporting (see Figure 1):

- decisions in various environments were routinely connected to the time of day, as well as the calendar;
- interconnections were required, both between different decision factors and the thresholds at which they would be active;
- the interface needed to accommodate different types of variables which we have categorized as continuous (such as flow of water), and discrete (such as containers).

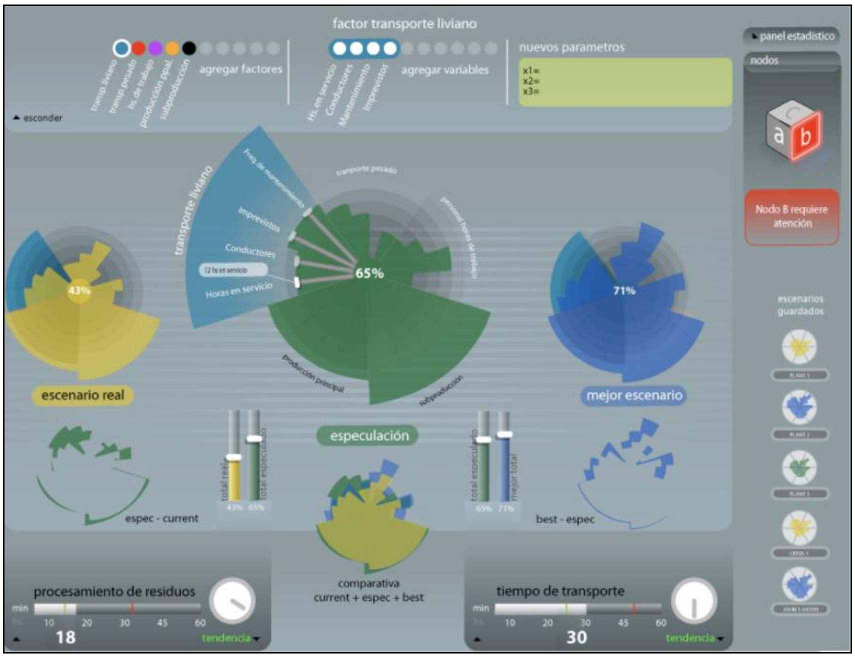

Figure.1 An earlier phase of this project provided a system for experimenting with decisions, based on the flower diagrams used by Florence Nightingale in reporting causes of death in the Crimean war.

Subsequent to the user study, we have re-conceptualized our design to include the missing components, as well as several others. We have developed a set of rich prospect browsing principles to help inform the design of new affordances in interfaces to digital collections of documents. Our gears enable digital affordances, which is to say, opportunities for actions, to take place. So far, we have identified six core affordances for the gears [25]:

- Experimenting with different decisions: our gears enable the user to compare multiple decisions that have been made in the past and experiment with different decision scenarios;
- Choosing a starting point: the user can choose a decision, a variable, or time/date as a starting point for experimenting with or reviewing decision;
- Displaying and managing decision variables: the interface presents a prospect view of the decision space which can be organized by either time/date or type of decision;
- Recognizing different variable types: we have began to create a system of gear design that uses the size, amount, shape, transparency, and colour to represent the type of decision being made and the nature of individual variables;
- Connecting decisions to time: the user can select days/hours as a sequence or independently, display a micro and/or a macro system view, and review past, present, and future (experimental) decisions;
- Tracking consequences: the user can review the impact of previous decisions on stages of operation and consequences of inaction.

We have also considered additional affordances for the system overall:

- File export: decision experiments, implemented decisions, and/or decision outcomes may need to be exported for use in other systems;

- Decision reporting: a decision summary based on date range, decision type, or manufacturing cycle may need to be generated; a playback function may be useful for training purposes; reporting should support numeric values and visuals;
- Access control and collaboration: some decisions may depend on one user’s input, while other decisions may require cross-departmental or even cross-site collaboration; multiple work areas may be required to control the type of information displayed to visitors or trainees, for example, versus plant managers.

We produced a working space consisting of a revision of Bradford Paley’s TextArc Calendar [26]. Since time had been identified as a critical component for decision making, we have used a calendar displaying both time and date as a framing device, inside which are located the visualizations of the factors in a particular decision (see Figure 2) [25]. These factors are in the form of nested, gear-like objects. Both the nesting and the gear metaphor represent the relationship which exists between the different variables within the decision making process. For example, a decision of whether or not to increase the production of one of the ice-cream flavors does not occur in isolation (see Table 1), but is connected to numerous other factors.

Table 1. Sample Decision Types

Task	**Inter-related components**
Should you buy or not buy more milk?	Alert level: medium Current milk inventory, storage capacity, past and future sales figures, projected use over time (plus milk expiry dates), delivery schedule (and availability of trucks and personnel)
Should you increase the production of one of the ice-cream flavors?	Alert level: low Current inventory (availability) of all relevant ingredients, purchase options for missing or low inventory ingredients, past and future sales figures for each flavour, delivery schedule (and availability of trucks and personnel), machine capacity (to accommodate increase in production)
Flammable waste is overflowing into a flare header not designed for liquids	Alert level: high Time to action, consequences of in-action, similar past scenarios and their outcomes, relevant personnel and their contact information, action alternatives

The HMI–DSS is meant to respond to these specific questions:

- What is the current status of the system overall, as well as those specific components that are my responsibility?
- Where are my resources (people and dollars) currently being allocated? What does this mean?
  How many resources do I have left? How best could they be used?
- In what phase or product area do I have the most or least sunk costs or value or competitive advantage?
- Is my distribution of resources aligned with value?
- Where is my pipeline of projects thin?
- At what point in the future might there be a gap in activity or revenues?

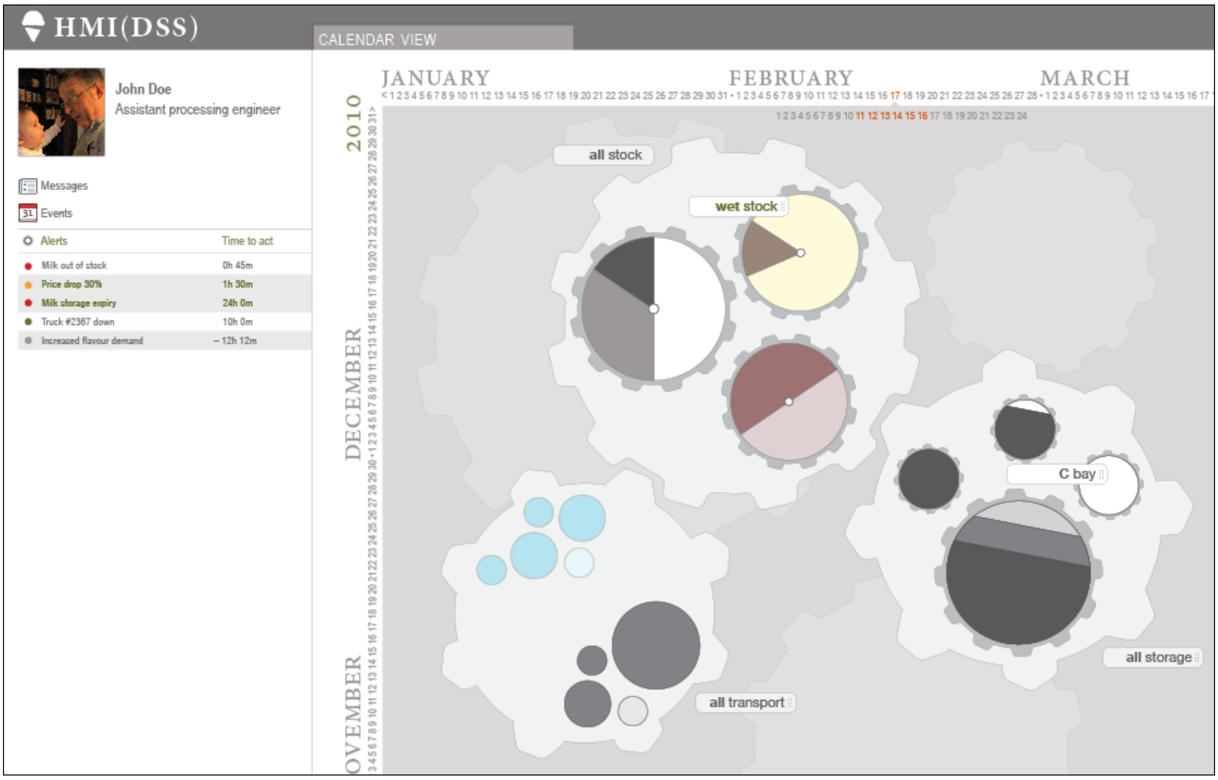

Figure 2. Our new design is framed using a calendar that indicates time and date, while the central space is occupied by widgets that support direct manipulation. This design allows the user to interactively adjust variables and view the outcomes and effects of their decisions.

The user can directly manipulate each nested gear [27] while s/he is in the process of addressing a particular decision. For every decision, a new set of gears appears, displaying the relevant variables and their relationships to one another. Since we are interested in accommodating the human aspect of the decision making process – the work experiences and knowledge that has been gathered over the years by those working in the field – simultaneously users can choose to display similar decisions that had been made in the past, together with their implementation and consequences (or lack thereof), and the contact information of the decision makers. Finally, users can run several decision experiments and compare their projected outcomes.

5. Conclusions

Human decision making does not occur in a vacuum. In fact, it often occurs in times of acute stress and intense time constraints, with consequences that can range from the mundane to the disastrous [4]. The kinds of choices people make and how they manage the day-to-day manufacturing operations can have profound consequences for other people and other processes. We believe that providing users with effective, usable, intelligent HMIs, that include both the qualitative and quantitative aspects of the decision making process, is an approach that can lead not only to a successful outcome for the design, but also to new insights into the kinds of design factors that need to be taken into consideration.

The next step in our iterative design research cycle is to test our experimental interface against some alternatives that are currently in use. In addition, in our next design phases we will turn our attention to the design of the following system components:

- the connection between the system and its trigger for action;
- visual differentiation between system inputs and outputs;
- visual differentiation between decisions which had been made in the past and decisions that are alternatives for the future;
- visual spectrum for the range of possible decision consequences;
- decision comparison;
- visual representations of abstract constructs;
- system alerts (visual and/or auditory); and
- fault tolerance.

From a theoretical perspective, we will continue our work in designing not just tools for machine control and decision making, but opportunities for actions within an HMI–DSS context, that were not previously possible.

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