Towards Intelligent Real-time Decision Support Systems for Industrial Milieu

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This paper is dedicated to Professor Mihai Drăgănescu

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Abstract: Decision support systems (DSS) are human-centered information systems meant to help managers placed on different authority levels to make more efficient and effective decisions for problems evincing an imperfect structure. These systems are very suitable information tools to apply to various management and control problems that are complex and complicated at the same time. Several issues concerning the modern trends to build anthropocentric systems are reviewed. Then the paper surveys several widely accepted concepts in the field of decision support systems and some specific aspects concerning real-time applications. Several artificial intelligence methods and their applicability to decision-making processes are reviewed next. The possible combination of artificial intelligence technologies with traditional numerical models within advanced decision support systems is discussed and an example is given.

Keywords: Artificial intelligence, decision, human factors, manufacturing, models.

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1. Introduction

The role and place of the human operator in industrial automation systems started to be seriously considered by engineers and equally by psychologists towards the middle of the 7th decade. Since then, this aspect has been constantly and growingly taken into consideration in view of famous accidents of highly automated systems and of incomplete fulfilment of hopes put in CIM systems [Martenson, 1996; Johanson, 1994].

The evaluation of the place of man in the system has known a realistic evolvement, triggered not only by practical engineer experience but also by the debates from academia circles. A long cherished dream of automatic engineers, that of developing "completely automated systems where man would be only a consumer" or "unmanned factories", tends to fade away – not only due to *ethical* or *social motivations*, but more important because the technical realisation of this dream proved to be *impossible.*

A possible solution seems to be the use of artificial intelligence methods (such as knowledge based systems) in the control of industrial systems, since these methods minimise the thinking effort in the left hemisphere of the human brain. Artificial neural networks, functioning similar with the right hemisphere of the human brain, became since 1990 also increasingly attractive, especially for problems that cannot be efficiently formalised with present human knowledge. Even so, "on field", due to strange combinations of external influences and circumstances, rare or new situations may appear that were not taken into consideration at design time. Already in 1990 Martin et al showed that "although AI and expert systems were successful in solving problems that resisted to classical numerical methods, their role remains confined to support functions, whereas the belief that evaluation by man of the computerised solutions may become superfluous is a very dangerous fallacy". Based on this observation, Martin et al (1991) recommend "appropriate automation", integrating technical, human, organisational, economical and cultural factors.

This paper aims at surveying from an anthropocentric perspective several concepts and technologies for decision support systems with particular emphasis on real time applications in manufacturing systems.

2. Anthropocentric Systems

2.1 Anthropocentric Manufacturing Systems

Anthropocentric manufacturing systems (AMS) emerged from convergent ideas with roots in the social sciences of the '50s. Kovacs and Munoz (1995) present a comparison between the anthropocentric approach (A) and the technology-centered approach (T) along several directions: *a) role of new technologies*: complement of human ability, regarding the increase of production flexibility, of product quality and of professional life quality (A), versus decrease of worker number and role (T); *b) activity content at operative level*: autonomy and creativity in accomplishing complex tasks at individual or group level (A), versus passive execution of simple tasks (T); *c) integration content and methods*: integration of enterprise components through training, development of social life, of communication and co-operation, increased accesses to information and participation in decision taking (A), versus integration of enterprise units by means of computer-aided centralization of information, decision and control (T); *d) work practice*: flexible, based on decentralization principles, work multivalence, horizontal and vertical task integration and on participation and co-operation (A), versus rigid, based on centralization, strict task separation at horizontal and vertical level associated with competence specialization (T).

2.2 Human-Centered Information Systems

Johanson (1994) shows that " failure and delay encountered in the implementation of CIM concepts" must be sought in organizational and personnel qualification problems. It seems that not only CIM must be considered but also HIM (human integrated manufacturing)". In a man-centered approach integration of man at all control levels must be considered starting with the early stages of a project.

In Filip (1995), 3 *key questions* are put from the perspective of the "man in system" and regarding the man – information tool interaction: a) does the information system help man to better perform his tasks? b) what is the impact of man- machine system on the performance of the controlled object? c) how is the quality of professional life affected by the information system?

Most older information systems were not used at the extent of promises and allocated budget because they were *unreliable*, *intolerant* (necessitating a thread of absolutely correct instructions in order to fulfill their functions), *impersonal* (the dialogue and offered functions were little personalized on the individual user) and *insufficient* (often an IT specialist was needed to solve situations). It is true that most of this problems have been solved by IT progress and by intense training, but nevertheless the problem of personalized systems according to the individual features of each user (such as temperament, training level, experience, emotional state) remains an open problem especially in industrial applications.

The second question requires an analysis of *effectiveness* (supply of necessary information) and *efficiency* (supply of information within a clear definition of user *classes* – roles – and real performance evaluation for *individuals* – actors – who interact with the information tool along the dynamic evolution of the controlled object). In the case of industrial information systems, the safety of the controlled object may be more important than productivity, effectiveness or efficiency. As Johanson (1994) pointed out, "in a technology-oriented approach the trend to let the information system take over some of the operator tasks may lead to disqualification and even to boredom under normal conditions and to catastrophic decisions in crisis situations".

This last observation is also a part of the answer to the last question, which answer holds an ethical and social aspect besides the technical one. Many years ago, Briefs (1981) stated, rather dramatically, that the computerisation of intellectual work seem to imply " a major threat to human creativity and to the conscious development ". This remark was motivated by "the trend to polarise people into two categories. The first one groups IT specialists, who capitalise and develop their knowledge and creativity by making more and more sophisticated tools. The second one represents the broad mass of users, who can accomplish their current tasks quickly and easy, without feeling tempted to develop an own in-depth perception of the new and confortable means of production".

As Filip (1995) noticed, "it is necessary to elaborate information systems that are not only precise, easy to use and attractive, all at a reasonable cost, but also stimulating to achieve new skills and knowledge and eventually to adopt new work techniques that allow a full capitalisation of individual creativity and intellectual skills". The aim to develop anthropocentric information systems applies today as well, but the designer finds little use in generally formulated objectives with no methods to rely on. It is possible to formulate derived objectives representing values for various attributes of information systems: a) *broad service range* (not "Procustian") – for the attribute "use "; b) *transparency* of system structure in regard to its capability to supply explanations – for the attribute "structure ", and c) growing adaptability and learning capabilities – for the attribute "construction"

3. DSS - Basic Concepts

The DSS appeared as a term in the early '70ies, together with managerial decision support systems. The same as with any new term, the significance of DSS was in the beginning a rather vague and controversed notion. While some people viewed it as a new redundant term used to describe a subset of MISs, some other argued it was a new label abusively used by some vendors to take advantage of a term in fashion. Since then many research and development activities and applications have witnessed that the DSS concept definitely meets a real need and there is a market for it (Holsapple and Whinston, 1996; Power, 2002)

3.1. Decision- Making Process

Decision- making (DM) process is a specific form of information processing that aims at setting- up an action plan under specific circumstances. There are some examples: setting-up an investment plan, sequencing the operations in a shop floor, managing a technical emergency a.s.o. Several models of a DM are reviewed in the sequel.

Nobel Prize winner H. Simon identifies three steps of the DM process, namely: a) "intelligence", consisting of activities such as data collection and analysis in order to recognise a decision problem, b) "design", including activities such as problem statement and production and evaluation of various potential solutions to the problem, and c) "choice", or selection of a feasible alternative to the implementation.

If a decision problem cannot be entirely clarified and all possible decision alternatives cannot be fully explored and evaluated before a choice is made then the problem is said to be "unstructured " or "semi-structured". If the problem were completely structured, an automatic device could have solved the problem without any human intervention. On the other hand, if the problem has no structure at all, nothing but hazard can help. If the problem is semi-structured a computer-aided decision can be envisaged.

The 'econological' model of the DM assumes that the decision-maker is fully informed and aims at extremizing one or several performance indicators in a rational manner. In this case the DM process consists in a series of steps such as: problem statement, definition of the criterion (criteria) for the evaluation of decision alternatives, listing and evaluation of all available alternatives, selection of the "best" alternative and its execution.

It is likely that other DM models are also applicable such as: a) the *"bounded rationality"* model, that assumes that decision-making considers more alternatives in a sequential rather than in a synoptic_way, use heuristic rules to identify promising alternatives and make then a choice based on a "satisfycing" criterion instead of an optimisation one; b) the *"implicit favourite"* model, that assumes that the decision-maker chooses an action plan by using in his/her judgement and expects the system to confirm his choice (Bahl, Hunt, 1984).

While the DSS based on the "econological" model are strongly normative, those systems that consider the other two models are said to be "passive".

In many problems, decisions are made by a group of persons instead of an individual. Because the *group decision* is either a combination of individual decisions or a result of the selection of one individual decision, this may not be "rational" in H. Simon's acceptance. The group decision is not necessarily the best choice or combination of individual decisions, even though those might be optimal, because various individuals might have various perspectives, goals, information bases and criteria of choice. Therefore, group decisions show a high "social" nature including possible conflicts of interest, different visions, influences and relations (De Michelis, 1996). Consequently, a group DSS needs an important communication facility.

4. DSS Technology

4.1. General Issues

A distinction should be made between a specific (application-oriented) DSSs (SDSS) and DSS tools. The former is used by particular decision-makers ("final users") to perform their specific tasks. Consequently, the systems must possess *application-specific* knowledge. The latter are used by "system builders" to construct the application systems. There are two categories of tools: integrated tools and basic tools. The *integrated* tools, called DSS "generators" (DSSG), are prefabricated systems oriented towards various application domains and functions and can be personalised for particular applications within the domain provided they are properly customised for the application characteristics and for the user's specific needs. The DSS *basic construction tools* can be general-purpose or specialised information technology tools. The first category covers hardware facilities such as PCs, workstations, or software components such as operating systems, compilers, editors, database management systems, spreadsheets, optimisation libraries, browsers, expert system shells, a.s.o. *Specialised technologies* are hardware and software tools such as sensors, specialised simulators, report generators, etc, that have been created for building new application DSSs or for improving the performances of the existing systems. An application DSS can be developed from either a system generator, to save time, or directly from the basic construction tools to optimise its performances.

The generic framework of a DSS, first proposed by Bonczek, Holsapple, and Whinston (1980) and refined later (Holsapple and Whinston, 1996), is quite general and can accommodate the most recent technologies and architectural solutions. It is based on three essential components: *Language [and Communications] Subsystem* (LS), b) *Knowledge Subsystem* (KS) and c) *Problem Processing Subsystem* (PPS

Recently, Power (2002) expanded Alter's DSS taxonomy and proposed a more complete and up-to-date framework to categorise various DSS in accordance with one main dimension (the dominant component) and three secondary dimensions (the target user, the degree of generality, and the enabling technology)

4.2. Real time DSS for Manufacturing

Most of the developments in the DSS domain have addressed business applications not involving any real time control. In the sequel, the real time decisions in industrial milieu will be considered. Bosman (1987) stated that control problems could be looked upon as a "natural extension" and as a "distinct element" of planning *decision making processes* (DMP) and Sprague (1987) stated that a DSS should support communication, supervisory, monitoring and alarming functions beside the traditional phases of the problem solving process.

Real time (RT) DMPs for control applications in manufacturing are characterised by several particular aspects such as: a) they involve continuous monitoring of the dynamic environment; b) they are short time horizon oriented and are carried out on a repetitive basis; c) they normally occur under time pressure; d) long-term effect are difficult to predict (Charturverdi et al, 1993). It is quite unlikely that an "econological" approach, involving optimisation, be technically possible for genuine RT DMPs. Satisfycing approaches, that reduce the search space at the expense of the decision quality, or fully automated DM systems (corresponding to the 10^{th} degree of automation in Sheridan's (1992) classification), if taken separately, cannot be accepted either, but for some exceptions.

At the same time, one can notice that genuine RT DMPs can come across in "crisis" situations only. For example, if a process unit must be shut down, due to an unexpected event, the production schedule of the entire plant might turn obsolete. The right decision will be top take the most appropriate compensation measures to "manage the crisis" over the time period needed to recomputed a new schedule or update the current one. In this case, a satisfying decision may be appropriate. If the crisis situation has been previously met with and successfully surpassed, an almost automated solution based on past decisions stored in the *information system* (IS) can be accepted and validated by the human operator. On the other hand, the minimisation of the probability of occurrences of crisis situations should be considered as one of the inputs (expressed as a set of constraints or/and objectives) in the scheduling problem. For example in a pulp and paper mill, a *unit plant* (UP) stop may cause drain the downstream *tank* (T) and overflow the upstream tank and so, shut/slow down the unit plants that are fed or feed those tanks respectively. Subsequent UP starting up normally implies dynamic regimes that determine variations of product quality. To prevent such situations, the schedule (the sequence of UP production rates) should be set so that stock levels in Ts compensate to as large extent as possible for UP stops or significant slowing down (Filip, 1995).

To sum up those ideas, one can add other specific desirable features to the particular subclass of information systems used in manufacturing control. An effective *real time DSS for manufacturing* (RT DSSfM) should support decisions on the preparation of "good" and "cautious" schedules as well as "ad hoc", pure RT decisions to solve crisis situations (Filip, 1995).

5. AI Based Decision- Making

As discussed in the previous section, practical experience has shown that, in many cases, the problems are either too complex for a rigorous mathematical formulation, or too costly to be solved by using but optimisation and simulation techniques. Moreover, an optimisation-based approach assumes an "econological" model of the DM process, but in real life, other models of DM, such as "bounded rationality" or "implicit favourite" are frequently met. To overcome these difficulties several alternatives based on artificial intelligence are used (Dhar and Stein, 1997, Filip, 2002). The term *Artificial Intelligence* (AI) currently indicates a branch of computer science aiming at making a computer reason in a manner similar to human reasoning.

5.1. Expert Systems

The *Expert System* (ES) is defined by E. Feigenbaum (the man who introduced the concept of "knowledge engineering") as "intelligent computer programs that use knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution". As in the case of the DSS, one can identify several categories of software products in connection with ES: application ES or "Knowledge Based Systems" (KBS), that are systems containing adequate domain knowledge which the end user resorts to for solving a specific type of problem; system "shells", that are prefabricated systems, valid for one or more problem types to support a straightforward knowledge acquisition and storage; basic tools such as the specialised programming languages LISP, PROLOG or object-oriented programming languages.

One can easily notice the similarity of the ES and DSS as presented in Section 4. Also several problem types such as prediction, simulation, planning and control are reported to be solved by using both ESs and traditional DSSs. At the same time, one can notice that while there are some voices from the DSS side uttering that ESs are only tools to incorporate into DSSs, the ES fans claim that DSS is only a term denoting applications of ESs. Even though those claims can be easily explained by the different backgrounds of tool constructors and system builders, there is indeed a fuzzy border between the two concepts. However a deeper analysis (Filip and Barbat, 1999) can identify some real differences between typical ESs and typical DSSs such as: a) the application domain is well-focused in the case of ES and it is rather vague, variable, and, sometimes, unpredictable in the case of the DSS; b) the information technology used is mainly based on symbolic computation in the ESs case and is heavily dependent on numerical models and database, in traditional cases; c) the user's initiative and attitude towards the system are more creative and free in the DSs case in contrast with ESs case, when the solution may be simply accepted or rejected.

5.2. Case-Based Reasoning

The basic idea of *Case-Based Reasoning* (CBR) consists in using solutions already found for previous similar problems to solve current decision problems. CBR assumes the existence of a stored collection of previously solved problems together with their solutions that have been proved feasible and acceptable. In contrast with the standard expert systems, which are based on deduction, CBR is based on induction.

The operation of CBR systems basically includes the first or all the three phases: a) selection from a knowledge base of one or several cases (decision situations) similar to the current one by using an adequate similarity measure criterion; b) adaptation of the selected cases to accommodate specific details of the problem to solve. This operation is performed by an expert system which is specialised in adaptation applications; "differential" rules are used by the CBR system to perform the reasoning on differences between the problems; c) storing and automatically indexing of the just processed case for further learning and later use.

5.3. Artificial Neural Networks

Artificial Neural Networks (ANN), also named connectionist systems, are apparently a last solution to resort to when all other methods fail because of a pronounced lack of the structure of a decision problem. The operation of ANN is based on two fundamental concepts: the parallel operation of several independent information processing units, and the learning law enabling processors adaptation to current information environment

Expert systems and ANNs agree on the idea of using the knowledge, but differ mainly on how to store the knowledge. This is a rather explicit (mainly rules or frames), understandable manner in the case of expert systems and implicit (weights, thresholds) manner, incomprehensible by the human in case of connectionist systems. Therefore while knowledge acquisition is more complex in case of ES and is simpler in case of ANN, the knowledge modification is relatively straightforward in case of ES but might require training from the very beginning in case a new element is added to ANN. If normal operation performance is aimed at, ANNs are faster, robuster and less sensitive to noise but lack "explanation facilities".

6. Knowledge Based DSS

6.1. Combined technologies

It has been noticed that some DSS are "oriented" towards the left hemisphere of the human brain and some others are oriented towards the right hemisphere. While in the first case, the quantitative and computational aspects are important in the second, pattern recognition and the reasoning based on analogy prevail. In this context, there is a significant trend towards combining the numerical models and the models that emulate the human reasoning to build advanced DSS.

Over the last three decades, traditional numerical models have, along with databases, been the essential ingredients of DSS. From an information technology perspective, their main advantages (Dutta, 1996) are: compactness, computational efficiency (if the model is correctly formulated) and the market availability of software products. On the other hand, they present several disadvantages. Because they are the result of intellectual processes of abstraction and idealisation, they can be applied to problems that possess a certain structure, which is hardly the case in many real-life problems. In addition, the use of numerical models requires that the user possesses certain skills to formulate and experiment the model. As it was shown in the previous section, the AI-based methods supporting decision-making are already promising alternatives and possible complements to numerical models. New terms such as "tandem systems", or "expert DSS-XDSS" were proposed to name the systems that combine numerical models with AI based techniques. A possible task assignment is given in Table 1 (inspired from Dutta, 1996). Even though the DSS generic framework (mentioned in Section 4.2) allows for a conceptual integration of AI based methods, for the time being, the results reported mainly refer specific applications and not general ones, due to technical difficulties arising from the different ways of storing data or of communicating parameters problems, and from system control issues (Dutta, 1996).

Table 1. A possible task assignment in DSS

	H	NM	ES	ANN	CBR
Intelligence					
Perception of DM situation	I/E		P		
Problem recognition	I/P				I
Design					
• Model selection	M/I		I		I
• Model building	M		I	P	
• Model validation	M				
• Model solving		E		P	
• Model experimentation	I/M		M/I		
Choice					
Solution adoption and release	E		P		

Legend: NM - numerical model. ES - rule based expert system. ANN - artificial neural network. CBR - case based reasoning. H - human decision-maker. P - possible. M - moderate. I - intensive. E - essential

6.2. Example

DISPATCHER is a series of DSSs. developed over a twenty-year time period. to solve various decision-making problems in the milieu of continuous 'pure material' process industries. The system initially addressed the short-term production-scheduling problem. Then it evolved in both function set supported and new technologies used in order to satisfy users' various requirements (see Figure 1). New supported functions such as tank sizing. maintenance planning and even acceptance and planning of raw materials or/and utility purchasing allow a certain degree of integration of functions within the [extended] enterprise (Filip, Bărbat. 1999).

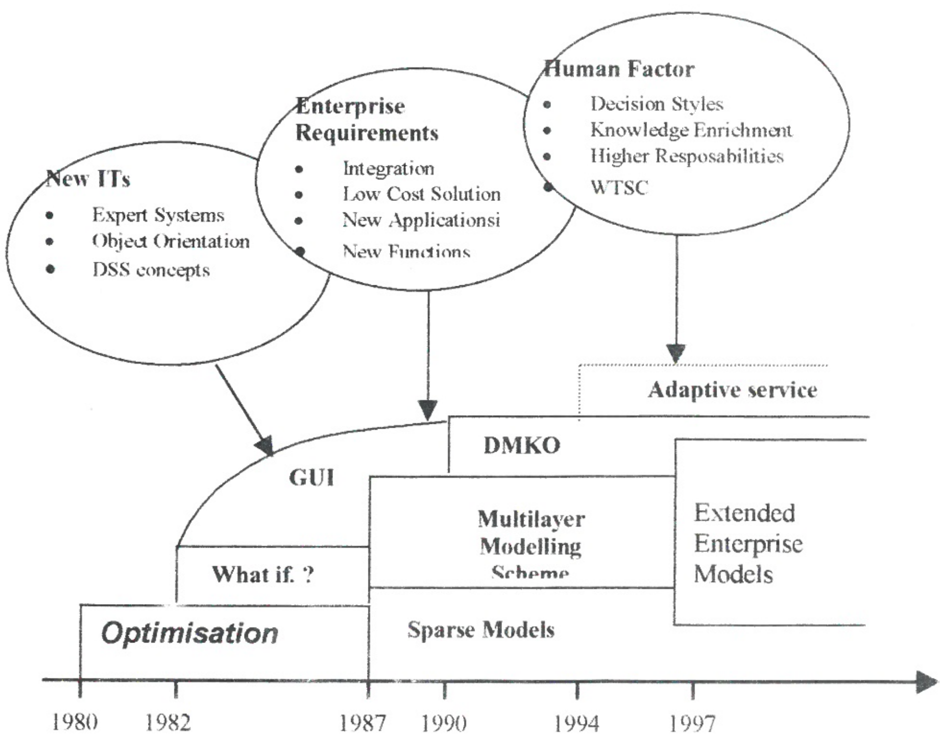

Figure 1.The evolution of the DSS DISPATCHER line[Filip. Barbat,1999)].

Numerous practical implementations of the standard version of DISPATCHER helped draw interesting conclusions. First, the system has been considered by most users as being flexible enough to support a wide range of applications and, in some cases, its utilisation migrated from the originally intended one. It has been used in crisis situations (mainly due to significant deviation from the schedule, to equipment failures or other emergencies) as well as in normal operation or in training applications. However, though the system is somehow transparent, and the users have sound *domain* ("what"- type) *knowledge* (DK), they have behaved in a "wise" or even "lazy" (Rasmunsen, 1983) manner, mainly trying to keep their mental load under an average *willing to spend capacity* (WTSC). This can be explained by the initial lack of *tool* ("how"-type) *knowledge* (TK) as well as by insufficient work motivation.

To fight the lack of TK and to stimulate users' creativity and quest for new skills, a *declarative model* of an "ambitious" and *knowledgeable operator* (DMKO) was proposed (Filip, 1993). DMKO is one component of a multilayer, modelling scheme that also includes: the external model (formulated in user's terms, b) the conceptual model (addressing the system builder's needs), and c) internal (performance model (meant for the use of the "toolsmith" programmer. It supports a) model building for various decision contexts, b) problem feasibility testing to propose corrective measures (for example limit relaxation or transformation of fixed/known perturbations into free variables etc.), c) automatically building the internal model from the external description, choosing the appropriate solving algorithm, d) experimenting the problem model, for example by producing a series of alternatives through modifying various parameters in answer to qualitative assessments (made by the user) of the quality of simulated solutions, followed by due explanations. To handle the complexity and diversity of the technologies used, object orientation has been adopted.

Efforts have been made to introduce new intelligence into the system, especially for evaluating user's behaviour so that DMKO (originally meant for supporting a certain "role") could dynamically adapt to specific needs of particular "actors", in an attempt at rendering the system less impersonal.

Of course, there are other reported results combining traditional numeric methods with KBS to build "hybrid" or "tandem" DSSfM. Apparently such systems are primarily meant for making numerical computation easier, including heuristics so that the space search for optimisation/simulation algorithms is adapted/reduced. It should be noted that the approach presented here is mainly human factor- centred and aims at increasing system acceptance rather than improving its computational performance.

7. Conclusions

Several important issues on the design of anthropocentric modern information systems were reviewed. DSS, as a particular kind of human- centred information system, was described with particular emphasis on real-time applications in the industrial milieu. The possible integration of the AI-based methods within DSS with the view to evolve DSS from simple job aids to sophisticated computerised decision assistants was dicussed

Several further developments have been foresighted such as:

- Incorporation and combination of newly developed numeric models and symbolic/sub-symbolic (connectionist) techniques in advanced, user-friendly DSS will continue; also the use of "fuzzy logic" methods are expected to be intensively used in an effort to reach the "unification" of man, numerical models, expert systems and artificial neural networks;
- Largely distributed group decision support systems that intensively use new, high-performance computer networks will be created so that an ever larger number of people from various sectors and geographical locations are able to communicate and make "co-decisions" in real-time in the context of new enterprise paradigms;
- Mobile communications and web technology will be ever more considered in DSS, thereby people will make co-decisions in "virtual teams", no matter where they are temporarily located;
- Other advanced information technologies such as virtual reality techniques (for simulating the work in highly hostile environments) or "speech computers" are likely to be utilised.

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