Development of the Subordinating Control Structure within the Hybrid Assembly System

Marshall Plan Scholarship Report

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Content

Preface

This report presents research work conducted during my stay as a visiting researcher at the Boston University. This visit was made possible through the Marshall Plan Scholarship program. The exchange presented a great opportunity and a privilege to gain valuable experience and insights to US higher education system. It served as a platform to meet respected scientists from various areas of expertise, expand my network of colleagues and to gain new friends.

I would like to express my deepest gratitude to the Marshall Plan foundation for supporting me financially during my stay in the USA. Without this scholarship it would have been very difficult to concentrate on the research. I would also like to express my gratitude to Ms Angelika Schweighart from the International office of Vienna University of Technology for all of her assistance and guidance during the application process.

I am very grateful to Professor Calin Belta from HyNESS lab at the Boston University for accepting me to his team and continuing a very promising international cooperation. He has been a great host and made me feel welcome from the start. Additionally, I want to thank the entire lab team for great cooperation, especially Cristian-Ioan Vasile, Junmin Wang and Igor Cizelj for interesting conversations, lunches and new friendships.

Last but not least, a very special thanks goes to my advisor, mentor and friend Professor Dr.sc. Dr. mult. h.c. Prof. h.c. Branko Katalinic. This application would not be possible without his mentorship and encouragement.

1. Modern product development

Modern product development is defined with the rise of product complexity, number of product variations and a shorter lifetime cycle [1]. The global market demands are increasing and there is a need for larger variety and number of products with simultaneous quality assurance and competitive prices. This means that newer, more complex products need to be designed, produced and shipped in shortest time possible with minimum number of errors and product recalls. All of these factors introduce new challenges and problems for modern assembly systems.

In order to answer and adapt to these new challenges, assembly systems need to evolve. They need to combine and merge with modern advancements from multiple fields of science and technology. Traditional approaches are no longer adequate for today's competitive market. With all of the advancements and technical breakthroughs, one area stands out – Information technologies (IT) sector. It has introduced great concepts, methods and opportunities for improving assembly system performance. These include artificial intelligence (AI), computer integration in production (CIP), design (CAD), manufacturing (CAM), computer vision, formal languages, genetic algorithms etc… Abilities and limitations of the control system, structure, scenarios, algorithms and methods used heavily influence the assembly system efficiency and productivity. By implementing some of mentioned IT methods in the various areas control structures it is possible to achieve great improvements and results in the overall performance of the system.

On the other hand, modern assembly systems need to be human centric [2] as shown on Fig. 1. There should be an incentive to keep the automated processes closely integrated and revolved around humans. The best results would arise from the cooperation between human – machine interaction. Such systems are characterized by adaptability, flexibility, self organization, autonomy and networking. They also need to be adaptable in real time, maintenance friendly, energy saving, life cycle manageable, capacity utilizing and tolerant to faults in processes.

The evolution of control structure is focused on the use of computer integration, intelligence and self organization for the improvement of assembly system efficiency [3]. The sophistication of control structures is proportionally increasing with the rise of working scenarios complexity. As a result the complete system is becoming very complex and more difficult to manage and to control. There are more and more subsystems that need to communicate with each other as well as increased number of shop floor elements that need to operate in harmony [5].

It is becoming very difficult for the human operator to cope with the vast amounts of data and sensory inputs. In such a highly dynamic and stressful working environment, he needs adequate and precise data in order to reach a quality decision in shortest time possible. There needs to be an intermediate information hub between the operator and the entire system. This hub needs to be "aware" of what is going on and what kind of information to present to the operator. The awareness is emerging from artificial intelligence concepts.

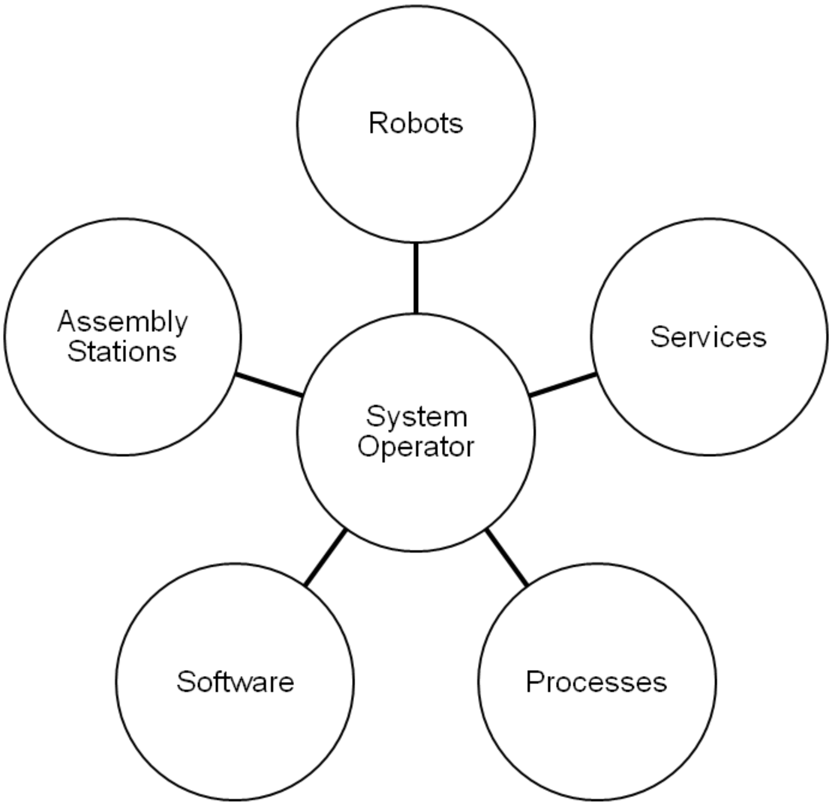

Fig.1. Human Centric Modern Assembly Systems

Modern assembly systems should be defined by the following characteristics [14]:

- High efficiency, adaptability and robustness in their realization of working scenarios
- User suitable and friendly for planning, controlling and monitoring
- Able to learn from past working cycles
- Use of Artificial Intelligence tools within the control structure

Chapter 2 discuses the main concepts behind knowledge based systems, the notion and types of knowledge as well as learning paradigms and how they translate to computer systems. Chapter 3 introduces knowledge based system's implementation in form of a decision support system as well as describes ideas behind decision making. Chapter 4 describes intelligent adviser module - decision support implementation concept within an assembly environment.

2. Knowledge based systems

One of the defining features of our civilization is to combine knowledge, resources and energy in order to produce goods. Doing this we are satisfying our needs and thus improving quality of life [20]. The defining manufacturing trend in the last two centuries has been a shift from the importance of skilled labor and labor intensive jobs towards knowledge and the use of knowledge. The most important key in such a new environment is the ability to successfully acquire, organize and control knowledge.

Based on all the indications, technology is an essential factor in the manufacturing and service industry [41]. Thanks to the ever increasing computer power and decreasing operational costs, a new generation of computing technology has emerged. It offers great potential to process, store and present knowledge. This emergence is known as artificial intelligence (AI) and under this broad term there are different types of approaches such as expert systems, semantic networks, computer vision, natural or formal languages etc… The main function of AI in knowledge based systems is representation (computer processing) and search reasoning (problem solving).

2.1. Knowledge based systems technology

The main feature of knowledge based systems technology is the ability to represent knowledge that uses AI techniques so that the computer systems can reason about this knowledge. In other words, the main goal is to achieve successful exchange of information between computers and humans. The information that the human is giving to the system needs not only to be stored, but meaningfully understood and vice versa, the data that the computer is presenting needs to be structured and formatted in a way that is presentable and understandable to the human. Can human experts present their knowledge effectively to the system? Can human experts understand what the system knows? Can the system use the information it has been given? Knowledge representation languages are dealing with these questions.

Out of many forms of knowledge here are a few [41]:

- descriptive definitions of problem domain specific terms (lathe, milling machine, saw…)
- description of domain objects that represent the object itself and its relationship to other object (automobiles have wheels, hatchback is an auto)
- description about actions and events (Tom changed the wheels in September…)
- description of the criteria for decision making or actions to be taken (if this then that)
- description of metaknowledge – “knowledge about knowledge” (system has all college books on file – and is aware of it). Analogy is trying to describe intuition. These way faster inquiries are possible.

Based on these knowledge representation techniques, we will focus on the following major types of knowledge based systems:

- Rule based / production systems [22,23]
- Semantic network systems [24]
- Frame based systems [22,25]

2.1.1. Rule based Systems / Production Systems

This structure was developed by Newell and Simon [27]. Production rule has the form of condition – action pairs. Rule based production system consists of:

1. Set of production rules

System consisting of a set of production rules (if – then rule / condition – action)

IF these *condition(s)* occur
THEN do these *action(s)*

2. Context: description of a given situation / problem context (simple list, large array…)

3. Interpreter: program whose job is to decide what to do next. During production it resolves conflicts and decides which production rule to fire next

During the execution of the production system, production rules are evaluated by matching the conditions of the production rules to the context, which is obtained either by entries in a database or from the user. When there is a match between the context and the conditions, the rule is fired.

Production System: Example

Production Rules:
R1: IF the headlight is NOT working,
THEN the electric system is NOT functioning

R2: IF the fuse is NOT blown,
THEN there is NO short circuit in the electrical system

R3: IF car cannot start, AND
The electric system is NOT functioning, AND
There is NO short circuit, AND
The electric cable is NOT loose,
THEN most likely, the battery needs to be recharged.

Initial context:
D1: Car cannot start
D2: The headlight is NOT working
D3: The fuse is NOT blown
D4: The electric cable is NOT loose

Fig.2. shows the matching procedure and additional conditions D5 and D6 after matching the R1-R3 rules to the D1-D4 conditions.

Additional context descriptions are added:
D5: The electric system is NOT functioning
D6: There is NO short circuit in the electrical system

CONCLUSION: The battery needs to be recharged.

New information in the context – D1, D4, D6 = R3 is satisfied and fired. It shows how the system reaches its conclusion by narrowing down the probable cause.

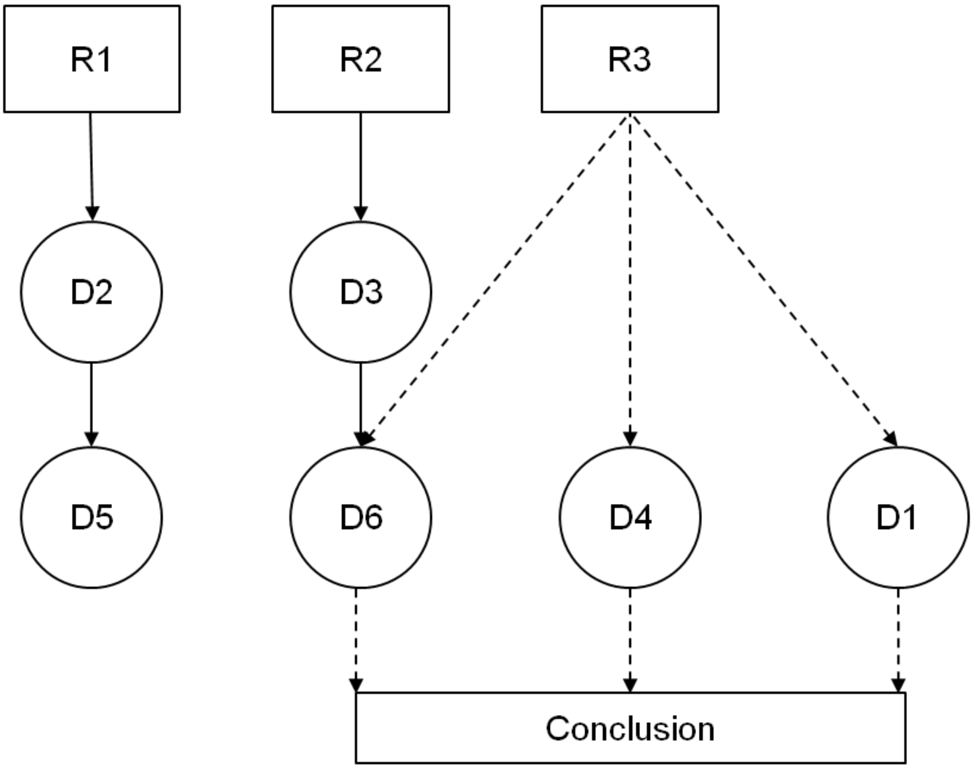

Fig.2. Production Rules - Example

Advantages:

- Production rules are easily added, deleted or modified without affecting other rules (good for rapid prototyping)
- Language and syntax provides a natural way of expressing knowledge
- Easy to maintain and development

Disadvantages:

- Inefficient use of computing power (matching) – it does not take advantage of efficient responsiveness or predetermined reasoning
- Undisciplined order and structure of rules construction - hard to differentiate between rules that perform different functions
- Knowledge base fragmentation makes it hard to maintain the integrity of the empirical knowledge base

2.1.2. Semantic network systems

Semantic network systems can be illustrated by nodes (objects, concepts, situations in a domain) and arcs (relationships between the nodes). They are used to represent knowledge about the properties of an object. The nodes lower in the net can inherit properties from the higher nodes without having to represent these properties explicitly in the net. This logic is shown on Fig.3. There is no need to explicitly specify that the automobile Ford Focus has wheels. That property is already described with the HAS statement – automobile HAS wheels. It is only needed to specify that Ford Focus ISA automobile. Semantic networks are widely used in natural language processing to represent languages.

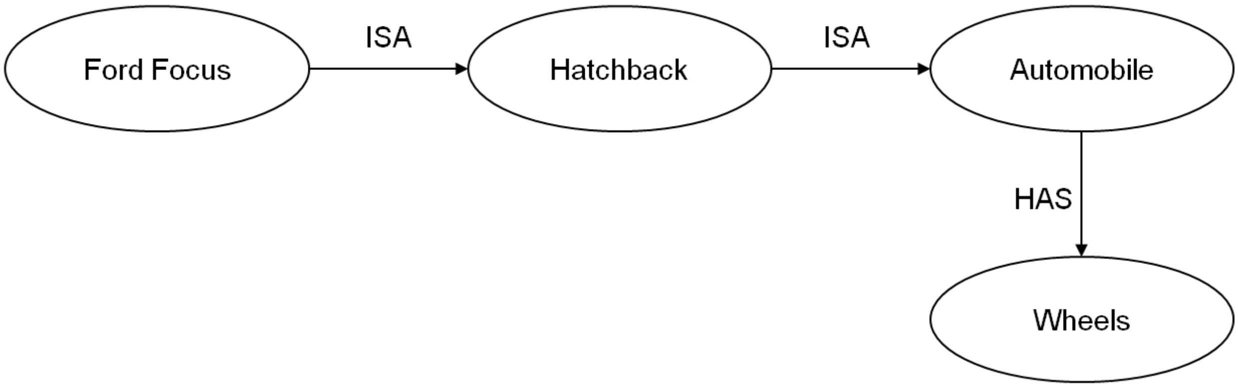

Fig.3. Semantic Network

2.1.3. Frame based systems

The notion of frames was first introduced by Marvin Minsky [31]. He described a frame as:

"A frame is a data structure for representing a stereotyped situation, like being in a certain kind of living room, or going to a child's birthday party. Attached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what to do if these expectations are not confirmed."

A frame is organized like a semantic network. It has a network of nodes and relations organized in a hierarchy, where the nodes lower in the network can inherit properties form nodes higher up in the network. The properties at each node are defined by a collection of attributes and their values.

Automobile frame:
Superclass: Vehicle
Subcalss: Hatchback
Number of wheels: 4
Number of doors:2, 4 (default 2)
Size of engine: 1.2, 1.4, 2.0 (default 1.4)

Ford Focus frame:
Member of: Hatchback
Number of doors: 2, 4 (default 4)
Size of engine: 1.4
Manufacturer: Ford
Model: Focus

The Ford Focus frame represents a specific automobile. Since Ford Focus is a member of the Hatchback frame, which is a subclass of the Automobile frame, it will inherit all their properties. Therefore, without being explicitly stated in its frame structure, Ford Focus inherits the property of having 4 wheels. Each slot is filled by a set of conditions and or defaults value where none is known. This enables reasoning based on seeking confirmation of expectations.

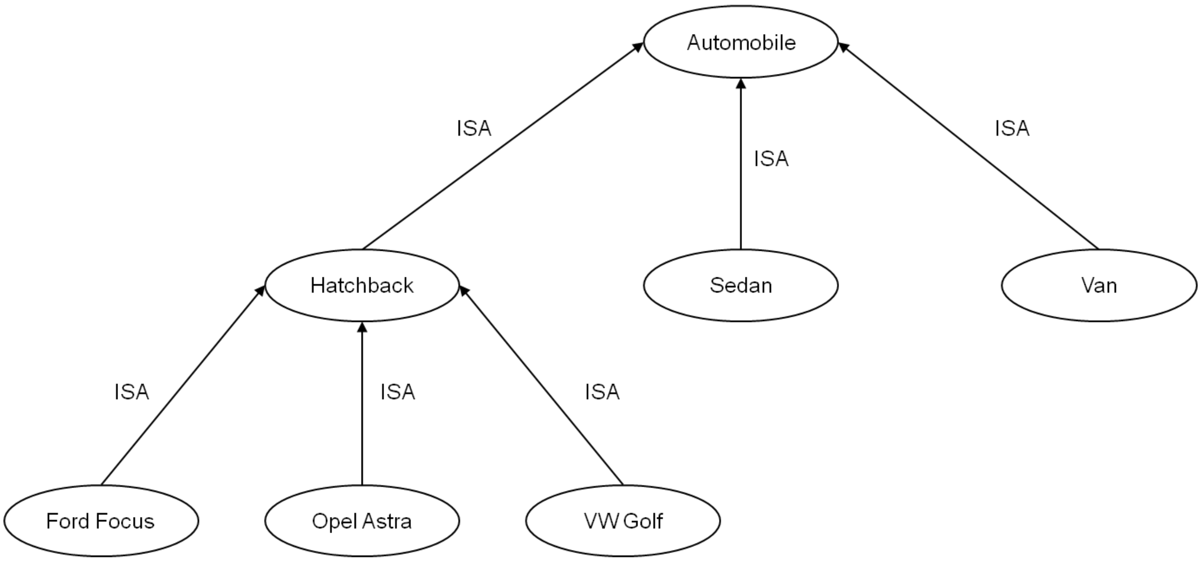

Fig.4. Frame Based System – Concept of an automobile

Procedures can be associated with a particular slot to drive the reasoning and to capture problem solving behavior of a system. This happens when the information in the slot has changed. Common procedures are (1235):

- *If added* procedure (new information added in the slot)
- *If removed* procedure (information deleted form the slot)
- *If needed* procedure (when information is needed but the slot is empty)

2.2. Learning

There are several definitions of learning. One description could be that learning is constructing or modifying representations of what is being experienced. (1235)

Another possible definition is (wiki):
"Learning is the act of acquiring new, or modifying and reinforcing, existing knowledge, behaviors, skills, values, or preferences and may involve synthesizing different types of information."

Based on Michalski, Carbonelli and Mitchell's discussion [34, 35], the following range of possible knowledge representations are mentioned:

- Parameters in algebraic expressions
- Decision trees
- Formal grammars
- Production rules
- Formal logic based expressions and related formalisms
- Graphs and networks
- Frames and schemas
- Computer programs and other procedural encodings
- Taxonomies or hierarchies
- Multiple representations

Several types of learning strategies are defined as in the papers [41]:

1) Learning by being told

This is the most straightforward learning method both for humans and machines. There is no transformation of information during this kind of learning. Emphasis is on how to manage the learned information and how to index it for fast retrieval.

In practice it can be used for identifying types of products, problem symptoms and possible repairs. Simple databases, taxonomies or hierarchical data structures may be appropriate.

2) Learning from instructions

It is being applied by humans in schools. It can be viewed as a more advanced form of "being told" learning. Learner has some basic capability of selecting and reformulating the information to integrate effectively with existing knowledge. An example is teaching the computer system about a new type of product. The system should already know about the product concept and only needs to acquire, store and retrieve the newly gained information.

3) Learning by deduction

In a sense this would not be considered true learning because all knowledge needs to be preprogrammed into the system. Deductive learning may be employed in order to improve the performance of deductions. If there is a long chain of deduction that leads to the same conclusion, it could be optimized by skipping certain steps.

4) Learning by analogy

Induction and deduction are being combined. Deduction is performed until dead end is reached. Further progress can be made if a related problem domain can be matched. For example, if there is no solution during deductive problem solving for a specific product type, further progress could be made if observing similar type of product and its problem solving / diagnosis procedure.

5) Learning by Induction (from examples)

For instance a system learns about acceptable values from examples. It needs to able to recognize the defining characteristics which have a direct influence and are differentiators. Learning from examples is particularly appropriate where there is a great amount of data or information available to the learner without a corresponding level of theory.

6) Learning by induction (by observing and discovery)

Main goal is to determine patterns and regularities that more or less explain the observations. This is often called unsupervised learning. This type is very useful where there is a great deal of rich data and very little theory about it. An analogy would be new human discoveries in scientific fields.

3. Decision support systems

In today's highly dynamic and competitive environments, good decision making is very important. The number of decisions that need to be made within a certain amount of time is drastically increasing. In addition to that, the quantity of data and information is getting bigger, broader and more diverse. Such conditions are becoming increasingly more stressful for the human operator – in this text human operators are called decision makers. Decision makers need all the help and assistance in order to cope with high levels of stress.

Decision support systems (DSS) are introduced to help the decision makers to be more productive, efficient and to reach quality decision for a given problem or situation. "Good or quality" decision is a broad term and cannot be universally applicable. It varies from situation to situation, depends on the working conditions, states of the system, competence of the decision maker, organization structure and many other factors.

For this reason, first it is necessary to define the very concept and ideas behind decision making and how use of knowledge influences it. Human analogy is a good example and one should start there. This chapter will also define different contexts in which decisions are being made, different decision makers as well as certain decision types.

3.1. Decisions

General agreement in literature is that decision is a choice about a "course of action" [15, 16] or choice of "strategy for action" [17].

Another definition is [43]: "*In psychology, decision-making is regarded as the cognitive process resulting in the selection of a belief or a course of action among several alternative possibilities. Every decision-making process produces a final choice that may or may not prompt action.*"

One interesting approach to observe and analyze decisions and decision making is knowledge based perspective [19], shown on Fig.5. In this approach a decision is a piece of knowledge. What happens when a decision is being made? It could be said that we are manufacturing new piece of knowledge, one that has not existed before. Manufacturing new knowledge could be achieved by transforming, restructuring or assembling already existing knowledge. Decisions could be viewed as new knowledge. During the creation of decisions, some additional by products can be produced. These could include alternatives that were not chosen. It is possible to reuse them later, or it is even possible that the decision making process itself has been improved.

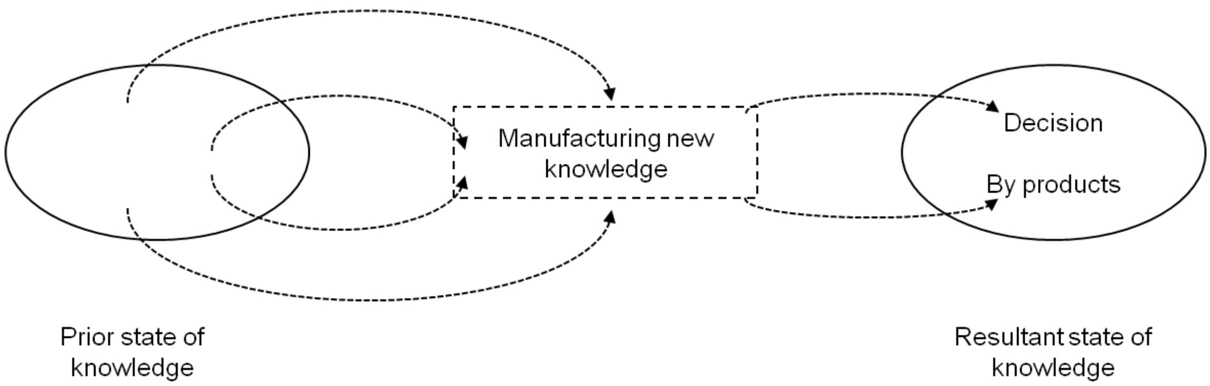

Fig.5. Knowledge based decision making

3.1.1. Decision context

Decisions are heavily influenced by the context in which they are being made. Context is in, most simple terms, a setting in which decisions are being made. They could be implying an organizational structure (top, middle or low), a newly or well established setting or a setting where the decision maker has full attention for a specific problem at a time or where he is having simulations decision making scenarios.

<u>Decision contexts:</u>

- Organizational
    - Top (strategic)
    - middle (management)
    - low (operational)

Moving from strategic to operational decision context:

- shorter decision times
- greater need for precise / detailed knowledge
- less need for wide knowledge
- less creativity

Top or strategic organizational structures refer to the strategic planning issues. They include tasks included such as organizational procedures, objective policies for acquisition, use and release of resources. Middle or management organizational structures refer to operational control issues such as ensuring that resources are acquired, used and released in order to meet objectives that were set by the policies from the top level. Low or operational organizational structures need to assure that specific tasks are carried in an efficient manner.

- Maturity of the situation
    - Newly established setting
    - Well established situation

What is a key difference in the decision context between a newly sorted and a well sorted situation? If there is a certain product that has been produced for a long time within a production line, decisions will be made much more easily and faster than in an environment where this product has become obsolete and now there is a need for a different, unproven production procedure.

- Degree of concurrence
    - Serial
    - Parallel

One decision process can distract the maker from another that is simultaneous. In doing this, it could actually happen that the maker has made both wrong or bad decisions because the lack of time and concentration and even that it can last longer than if he made them one after another.

3.1.2.*Decision types*

Besides contexts in which decisions are being made, types of decisions influence the nature of decision making. The classification used to differentiate the types is based on the structural and negotiation scheme [42].

Decision types:
- structured (programmable)
- unstructured (unprogrammable)
- negotiated
- unilateral

Structured types are also called programmable decisions (Vecchio). The reason is that all the actions leading to a fully structured decision can be programmed. This can happen in a well known and organized situation. Instructions in this case are procedural knowledge and rules could be applied (if / then).

Unstructured types are also referred to as un programmable. It is very difficult to create a set of rules that would cover all the case scenarios. Such scenarios are characterized by emergent context, novelty and elusive issues and rareness. In order to cope with such conditions there is a need for ingenuity, creativity, imagination, intuition and exploration.

Negotiated decisions are being reached when all individuals / units agree on a single mutual option. All participants have to agree albeit in a varying degree of satisfaction.

Unilateral decisions also being reached by multiple participants but unlike negotiated decisions, only one person can decide the final outcome. He can be influenced by all others to a varying degree, but the final decision is his/hers.

3.1.3. Decision maker

Decision making can include a single or multiple participants. In the case that a single participant is the decision maker, a unilateral decision process is taking place. This implies that all paths are leading to a single hub, which can be represented by a human or computer. If the computer is making the final decision, the system is no longer called “decision support system”, but rather “decision making system”. If the decisions are made by multiple participants, the methods used could be either unilateral or negotiated. During the unilateral decision making other participants can influence the main one. During a negotiated decision making process, multiple participants share the responsibility equally. Fig.6. shows all the kinds of decision makers. The multiparticipant classifications are made according to the varying duties of participants and their interactions with each other.

Next chapter will focus around the individual decision maker or the human operator. Using his mental skills, he is able to acquire and use his knowledge in order to solve problems. Two main methods of acquiring new knowledge are training and experience.

Individual decision maker characteristics [42]:
- intelligence
- knowledge
- training
- experience
- personality
- cognitive style

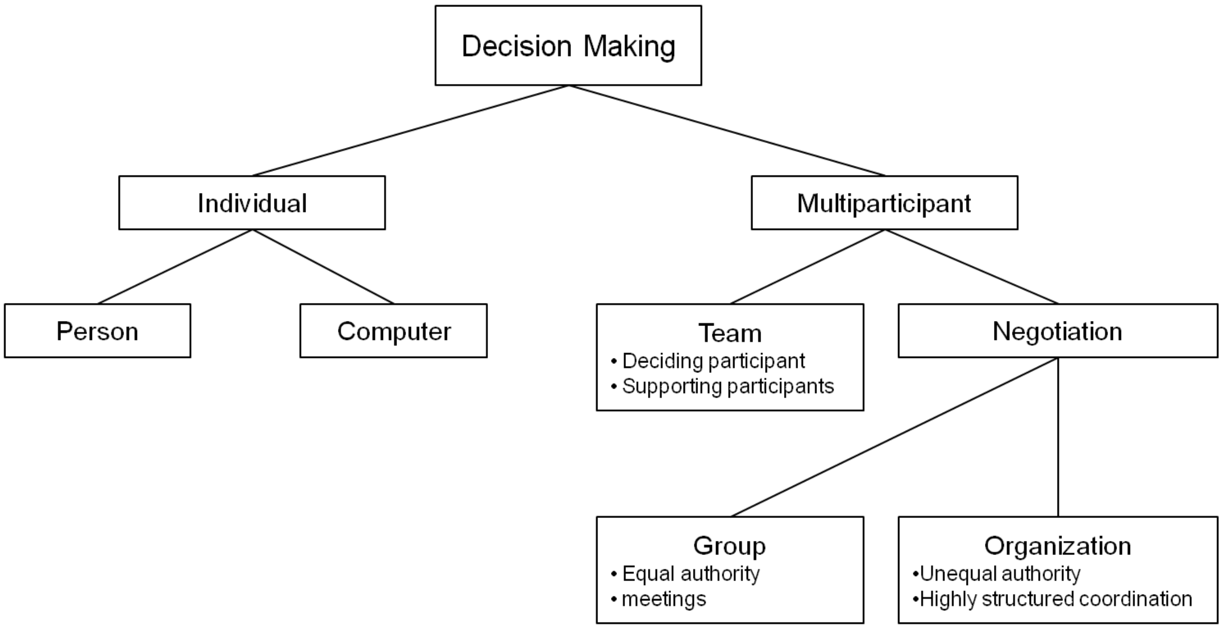

Fig.6. Types of Decision Makers

3.1.4. Need for support

There are inherit costs with developing and purchasing decision support systems, as well as included costs with learning, developing, using and maintaining them. A decision making environment is very stressful and knowledge intensive for the operator. It can become very hard to reach a decision. To help him as much as possible, one option is to form a large group of people, or a decision support team. But this could become very expensive in terms of paying and educating the staff. For this reason, companies are very interested in investing in DSS systems. The need for support can be expressed through limiting factors. First there are cognitive limitations of humans, second there are economic factors included with educating operators and as third, there is a time limit in which a decision needs to be made.

Limits:
- cognitive
- economic
- temporal

Nature of support:
- alert user to a decision making opportunity / challenge
- recognize problems
- solve problems
- extend user ability (acquire, transform, explore knowledge)
- advise, expectations, evaluations, facts, analysis, designs
- stimulate user perception, imagination, creative insight
- coordinate interactions among participants

3.2. Knowledge

As discussed in previous chapter, it is important to understand the concept and notion of knowledge and how it is connected with decision making. The question of knowledge and representation is vital to the design of computer based systems interceded for knowledge amplification. Fig.7. shows the principle of successful communication between the decision maker and the DSS system. In order for a successful communication there needs to be a two way exchange of information. For the DSS system to understand what the command is there needs to be a interpretation of inputs. For the decision maker to understand the results there needs to be a good method of presenting the information.

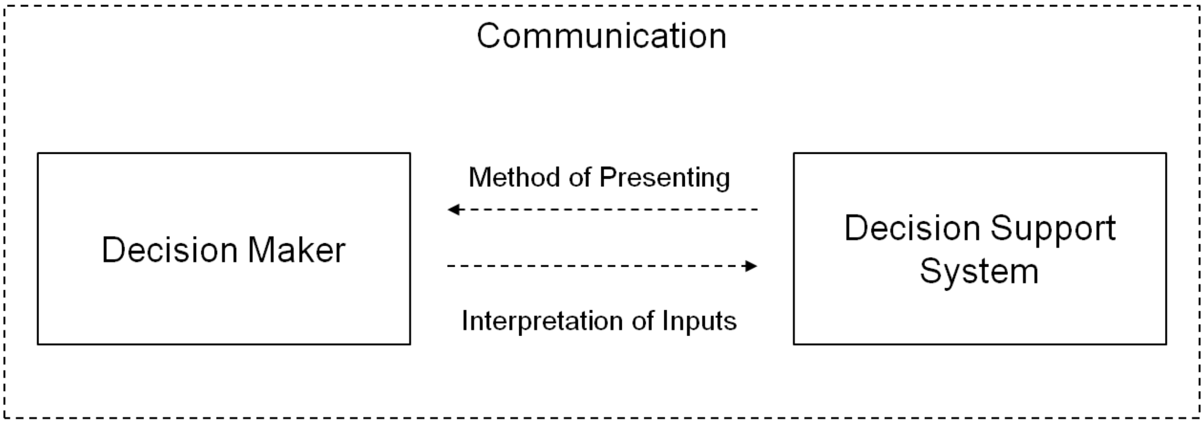

Fig.7. Communication with DSS

Computer based techniques for managing knowledge:

- Text, rules, database and forms management
- report generation
- business graphics
- spreadsheet analysis
- solvers
- programming

There are six main types of knowledge important for DSS systems [42]. Knowledge about the states is known as descriptive knowledge. It answers the question “what”. Procedural knowledge is referring to a step by step procedure on how to accomplish a task. It answers the question “how”. Third knowledge type is reasoning knowledge and it specifies what conclusion can be drawn when a certain situation exists. It answers the question “why”. Linguistic knowledge is the basis for acquiring every other type of knowledge, or in other words basis for communication. Assimilative knowledge is a sort of a filter for deciding what acceptable new knowledge is. It is used for not accepting low quality or unusable knowledge. Presentation knowledge is inverse to linguistics knowledge. It is used for giving out pieces of information.

Types of knowledge:

- Primary
    - Descriptive (“What”)
    - Procedural (“How”)
    - Reasoning (“Why”)
- Secondary
    - Linguistics
    - Assimilative
    - Presentation

3.3. DSS overview

DSS refers to a computerized supporting participant in decision making [42]. This section will describe the general purposes of DS systems, developing trends, some of the benefits and limitation of using such systems as well as displaying DSS possibilities in contrast to a human metaphor. This will allow understanding the ideas, concepts and reasons of using DSS. The following list shows some of the possible purposes that DS systems could be used for.

Purposes:
- improving one or more decision maker's abilities and productivity
- Increasing efficiency of decisions
- Knowledge collection (What is the current system situation?)
- Formulate plans for analysis and action
- Supplement decision maker abilities (What if this happens?)
- Problem recognition
- Improve makers evaluation / implementation / governing abilities
- Ensuring smooth and rapid problem solving
- Manage knowledge (enhance users ability to represent and process knowledge)

3.3.1. Development trends / History

50's and 60's

Data processing systems (DP) - They were used to automate the handling of large number of transactions during:
- Record keeping
- Transaction generation

Management information systems (MIS) – They were used for periodic reports or as regular snapshots of what has been happening in the organization.

Negatives:
- Not for dynamic environments
- State of information
- Relevant info can be incomplete, difficult to grasp, unfocused, difficult to find, in need for further processing
- Issued periodically (hourly, daily, weekly)
- Focused on managing descriptive knowledge

70's – first DSS notion used in corporate planning, water quality planning, banking…
80's – introduction of the microchip computer, use of electronic spreadsheets, management science, packages, ad-hoc query…
90's – Artificial intelligence to manage reasonable knowledge (leads to expert systems)
00's and further progress – user makes queries in his own language (no need for query languages)

3.3.2. Decision support systems

Decision maker should have immediate focused, clear access to necessary information which is needed in the specific moment when a decision needs to be made. This will allow him to make a "on time" quality decision with minimum hesitation or subsequent questioning regarding the validity of the decision. The following list shows some of the desired traits that a DSS system should posses:

- Specific knowledge regarding the working environment (relevant data)
- Acquire and maintain types of knowledge
- Ability to present knowledge for problem solving
- Interaction with the decision maker
    - Through series of questions
    - User states a command

Benefits:

- Good fit between the natures of DSS, the decision maker and the decision context.
- Augments decision makers abilities
- Solve problems otherwise skipped or time consuming
- Fast solutions / reliable
- Stimulate decision maker thoughts
- New ways of thinking
- Justify decision maker decision / his position
- Increase competitiveness of the organization

Limits:

- Human skills (creativity, intuition, imagination)
- Knowledge constraints and ability to learn
- Knowledge type constraints
- Hardware limits
- Interaction language
- Coordination of multiple DSS
- Balance between bad decision maker and overdependence on DSS

3.4. DSS Possibilities as a human metaphor

- Accepting decision maker requests
- Make responses to decision maker
- Posses knowledge
- Process knowledge

3.4.1. Accepting decision maker requests

- For providing knowledge
    - If the decision maker is not aware of DSS methods
    - Detailed step by step specification on how the DSS got the solution
- For accepting knowledge
    - From multiple sources – it is possible that DSS does not understand a request
        - Needs further clarification
        - If it does not understand, the procedure ends
- Comprehension: interaction between both sides (phrasing)
- Learning
    - formal training (initial, ongoing)
    - experience

3.4.2. Making responses to decision maker

a) Appearance (syntax) – response from DSS: in what shape, form or level of detail will the decision maker be presented with the information?

b) Meaning (semantics) – request to DSS: in what way will the decision maker perform a request form the computer system. Will it be a guided series of questions or inputs or a natural semantic conversation?

Response:

- what to say
- way to say it (audio / visual):
    - chart, drawing, graph, form, narrative, table, outline, image

How to choose a method of presentation – for instance a user can specify what kind of graph.

Response can be to:

- seek clarification of a request
- provide knowledge to support decision
- provide clarification of a response
- seek additional knowledge

If response from DSS is not understood – maker seeks further clarification (change the presentation of the information):

- table to graph
- more / less details (week / month)…

3.4.3. Possessing knowledge

- DSS should have a knowledge repository and have the abilities to process it
- DSS should acquire knowledge by:
    - direct observation
    - sensing events
    - experience
    - feedback
- Types of knowledge DSS can acquire:
    - descriptive
    - procedural
    - reasoning
    - linguistic
    - presentation
    - assimilative

3.4.4. Processing knowledge

- ability to acquire and use knowledge to guide the processing of another knowledge
- ability to effectively coordinate its use of different knowledge processing abilities

3.5. DSS Architecture

Consists of generic framework (essential elements of a DSS):

- language system (LS)
- presentation system (PS)
- knowledge system (KS)
- problem processing system (PPS)

3.5.1. DSS Generic Framework

- LS: all messages DSS can accept (requests)
- PS: all messages DSS can emit (responses)
- KS: knowledge DSS has stored
- PPS: uses LS, PS and KS for knowledge processing (active part of DSS / software for recognition and problem solving during decision making)

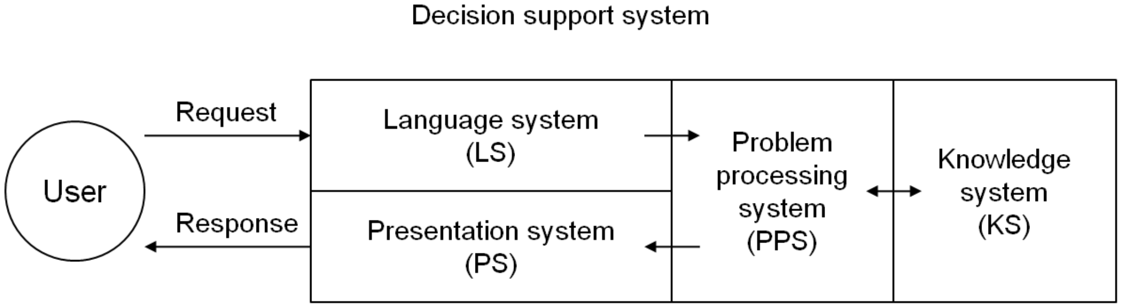

Fig.8. Generic DSS Framework

<u>Generic framework</u>:

- Perception – decoding user request + find paths to needed knowledge in KS
- Problem recognition
- Model formulation
- Analysis
- Integration of procedural knowledge so a CPU understands (PPS and KS can incorporate AI)

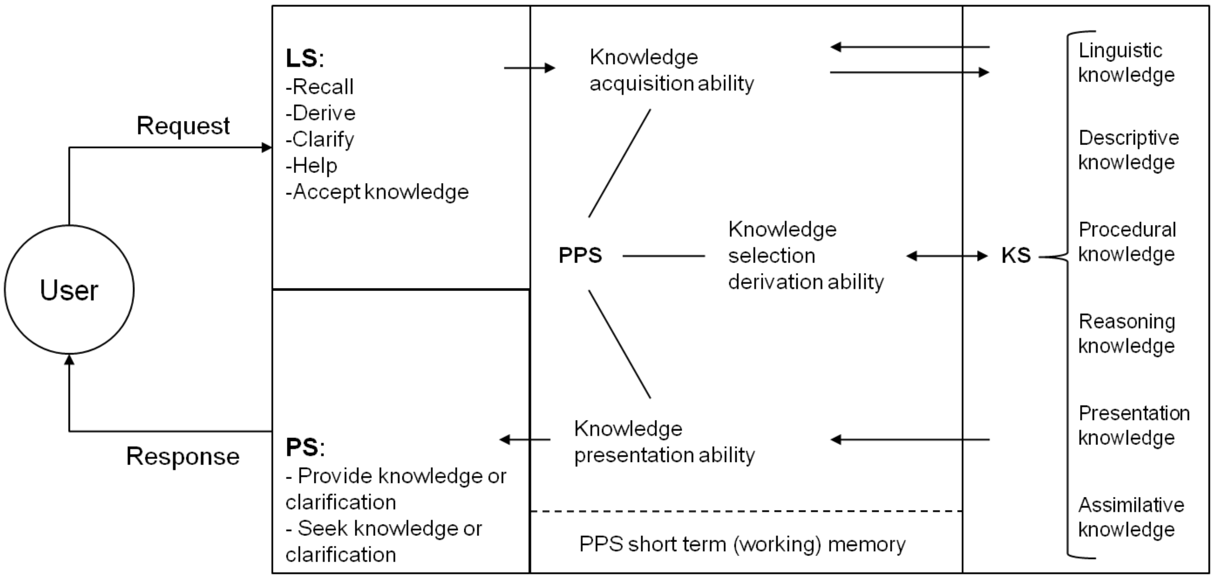

Fig.9. Detailed DSS Framework

Problem processing system (PPS) is used as a short term (working) memory. It contains pieces of knowledge needed during the problem solving activities. It represents the ability of the system. Additional function is to prevent the knowledge system (KS) to become clogged. Clogging is avoided with the use of PPS because it does not have to repeatedly search through the vast knowledge database each time a request or search is made.

PPS:

- Knowledge acquisition
- Knowledge presentation
- Knowledge selection / derivation (request for solution)

3.5.2. Model Based DSS

It is used in order to recognize the existence of descriptive knowledge in KS. Main function is to construct large procedures by assembling or sequencing modules that are needed.

Model management systems

- Database
- Model base
- Software system
  - database management software (DBMS)
  - Model base management software (MBMS)
  - Dialog generator and management system (DGMS): defines what a user can request and see
- Model base - composed of program modules known as solvers (procedural knowledge or models)

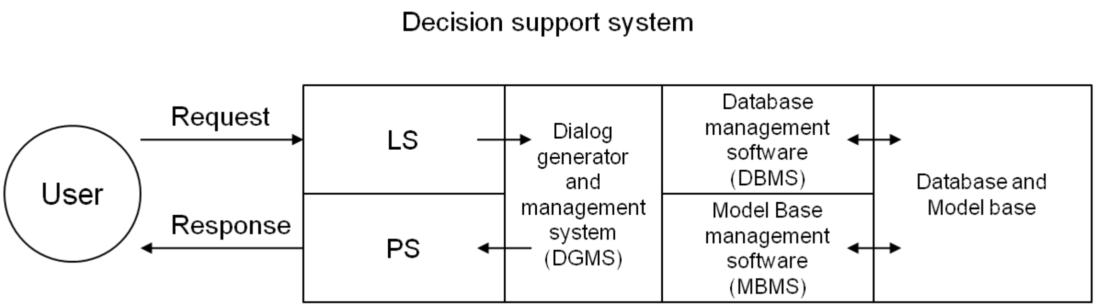

Fig.10. Model based DSS

3.5.3. Text based and spreadsheet DSS

- These DS systems are used as a knowledge management technique – important for descriptive knowledge.
- Database management – good for large amount of structured data
- Text management – descriptive knowledge not yet formally organized into fields and records
- Hypertext – ad hoc associative links
- Spreadsheets are used to hold descriptive and procedural pieces of knowledge
- Procedural pieces are represented as cell constants.
- Descriptive pieces are represented as cell formulae.

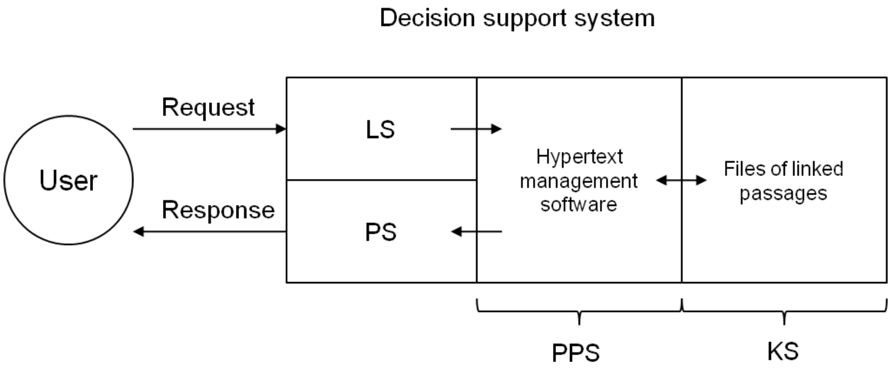

Fig.11. Text based and Spreadsheet based DSS

3.5.4. Expert systems

- special kind of DSS
- they rely on knowledge management techniques (rule management)
- knowledge represented as rules – each with premise and conclusion
- rules specify reasoning relationships among state variables
- inference engine: software which gives values to variables without a value

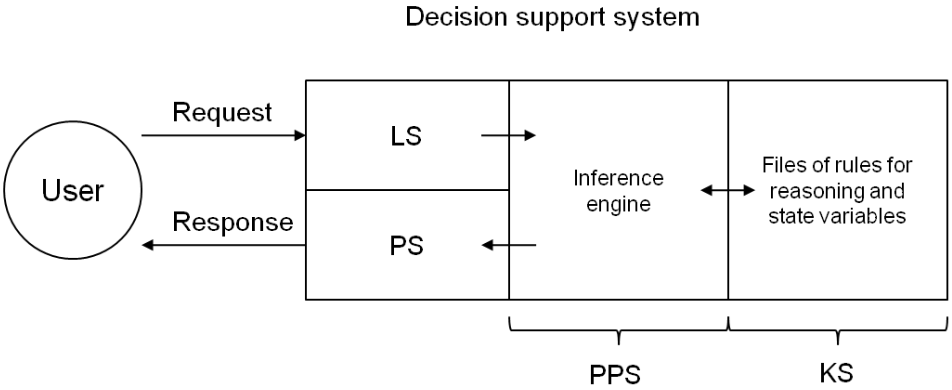

Fig.12. Expert System

3.5.5. Multi dimensional DSS

- solves limitation of just choosing a specific type of DSS – hybrid approach
- Full spectrum of knowledge representation (not just combination of 1 or 2)
- PPS – has to posses procedural abilities for each of the representations
- GPPS – generalized PPS – solution on how to integrate the software capabilities traditionally found in separate tools

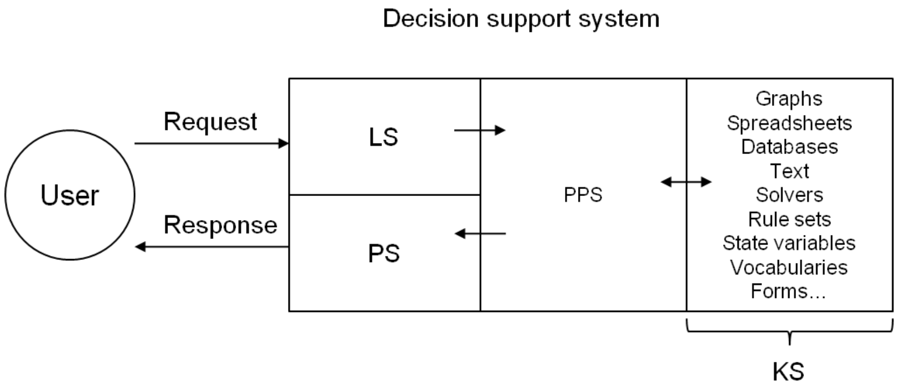

Fig.13. Multi dimensional DSS

4. Intelligent adviser module

After the introduction of several concepts and ideas regarding knowledge, and decision making, the intelligent adviser module represents the realization within hybrid subordinate control structure as discussed in [14]. Intelligent adviser module is a local assembly system data gathering and analysis diagnostic software tool [14]. It collects, processes and stores relevant information. Intelligent adviser module is not directly involved in control but rather amplifies the cognitive performance of the system operator and assists him during decision making process.

Intelligent adviser module has the following functions [14]:

1) Progress of realization of planned scenarios is possible to determine from the analysis of the target and the actual state of the system. If the difference is close to critical the adviser module advices the operator what to do in order to keep the realization of working scenarios. In case that the planned scenario cannot be realized it is necessary to repair the working scenario or to replace it with a new one. Adviser module proposes what to do.

2) Data analysis. Main control information flow is between central control computer and the control system of all the facilities. Through this channel there is a real time exchange of information in both directions. With this channel the control computer gives instructions, commands and data to people, machines and robots. They give feedback information about the realization status and the equipment status. Adviser module continuously analyzes the information from the main control information flow. If he recognizes significant deviations in working conditions (breakdowns, errors, malfunctions) and it proposes solutions to the operator.

3) It has the ability to learn. There is almost always a difference between planned activities and their realization in the real world. System efficiency directly depends on this difference. Smaller difference means higher system efficiency. Adviser module has the ability to precisely predict the duration of future activities based on the experience of planning and execution of equal or similar operations from the past. This ability is described as learning from the past for the efficiency in the future. This is very important for the planning of future activities.

4.1. Intelligent adviser module role

Fig.[14] shows the role of the intelligent adviser module in the subordinating control structure. Adviser Module serves as an informational interface between the system operator and the rest of the assembly system. Intelligent adviser module communicates with the following modules within the subordinating control structure as described in [14]:

- System Operator
- Pool of Orders
- Stock of Resources
- Criterion of Planning Module
- Scheduling Module
- Actual and Target State Data Module

It communicates with the following shop floor components within the facility:

- Assembly Stations
- Robots
- Shop Floor Operators

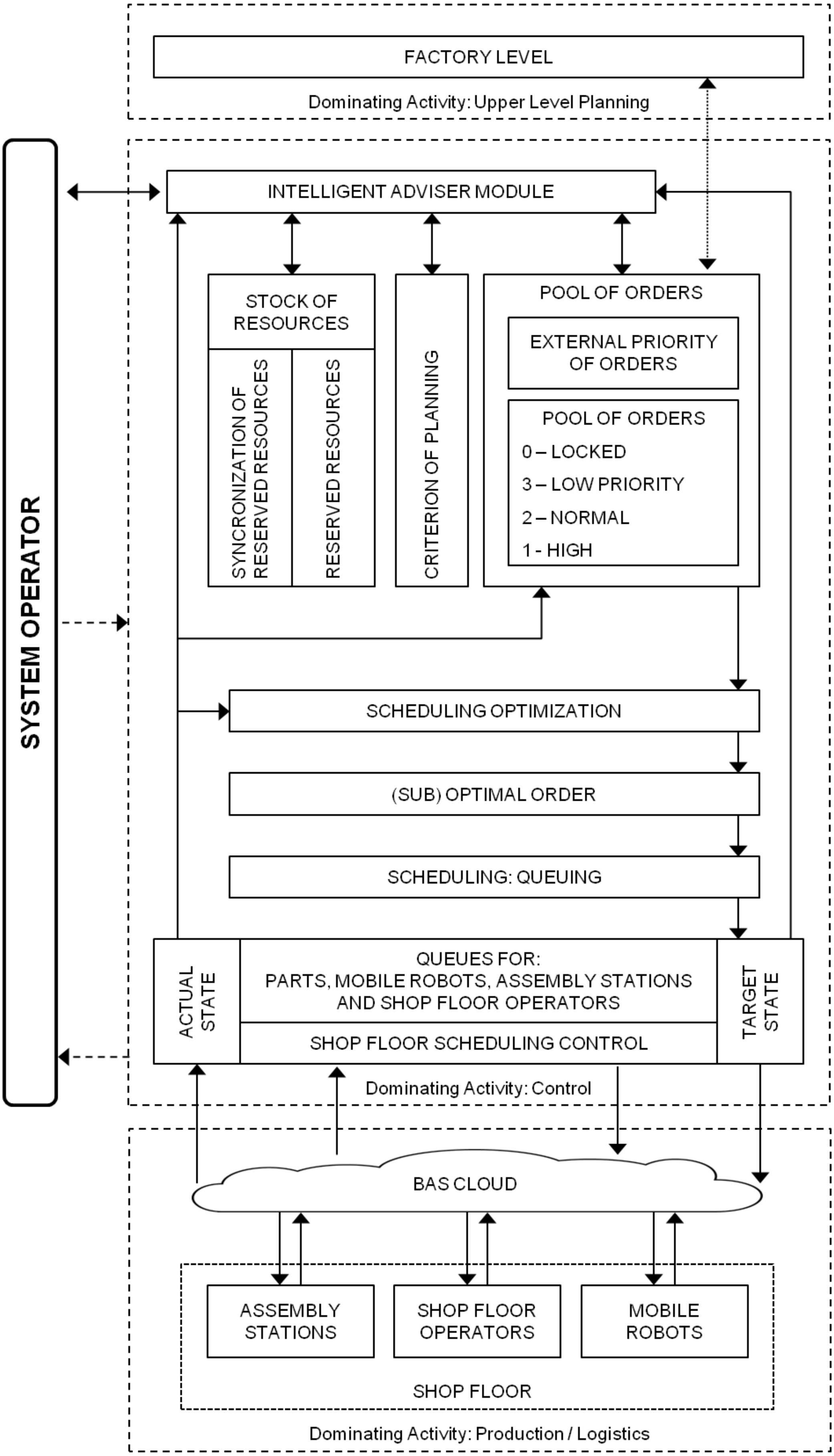

Fig.14. Role of the Intelligent Adviser Module

These modules are all working in order to execute working scenarios which start with orders and finish with assembled products as shown on Fig. 15. During the execution of a working cycle internal and external resources are being used. These resources are also a potential source of disturbances. There can be a shortage or a defective batch of parts. Human employees can get sick or distracted. There can be a power outage or just simply a machine malfunction.

Some jobs and operations during the assembly or manufacturing are very procedural and can be summarized with rules. These kinds of jobs are programmable and the need for the operator is very low. During that time, it is very tedious and unnecessary for the operator to engage with such tasks. On the other hand, there are cases in which the need for the operator is very high. These situations are unpredictable, random and unprogrammable. They need quick thinking, intuition, and resourcefulness. These are some of the possible situations where the need for the operator is very high:

- During the planning of working scenarios
- When the realization of working scenarios is not running according to the planning
- When malfunctions of equipment occur

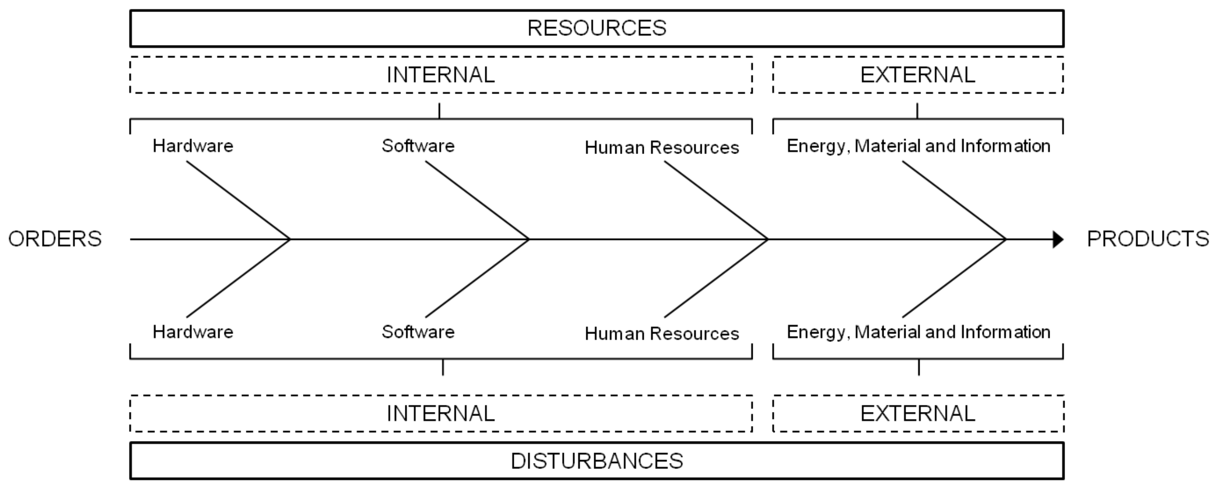

Fig.15. Resources and Disturbances

The main objective is to achieve harmony between the two levels of organizational structures. The first level is a top - down, subordinating control structure, from which queues and tasks are formed. This is commonly known as hierarchy. In this structure all commands are coming from one source - the system operator. The second level is the execution level. The execution level can represent any kind of shop floor organizational structure. It can be a production or an assembly system. The goal is always the same: to achieve the balance between the target state and the actual state.

- Target state represents planned activities. It is what should happen.
- The actual state represents the realization of the planned activities. It is what has happened in the real and unpredictable world.

As mentioned in the introduction, demands on system operators are increasing. In a ever increasing stressful environment, the need of a proposed adviser module is obvious. Such a system will bring a certain number of advantages. The main principle, one that it amplifies human knowledge and assists him, refers to coexistence between humans and automation systems. This allows for a development of human centric systems, which is very welcome in today's industrial environment. These systems will in addition of securing jobs, ensure the realization of increased efficiency in decision making process.

Intelligent adviser module has the following advantages:

- Flexible and universal: this system can be used in any modern production or assembly facility
- detection of early irregularities in the production / assembly
- control experts skill, experience and intuition combined with the data stored in the adviser module help to achieve quick and effective solutions
- reduces stressful decision making environment for the system operator

Intelligent adviser module has the following disadvantages:

- false warnings are possible
- effectiveness improves with higher amounts of stored data. This means that younger systems are less accurate
- rejection of computer suggestions by human operators ("I know better than a machine" principle)

The characteristics comparison between the system operator and the intelligent adviser module are shown in Table. 1.

Table 1. Characteristics Comparison

Characteristic	**System Operator**	**Intelligent Adviser Module**
Intuition	High	Low
Short term memory	High	High
Long term memory	Low	High
Learning	Natural ability to learn	Limited technical ability to learn
Analysis	Medium	High
Robustness	Easily tired	Does not need rest

5. Conclusion

The world has truly become a global village. As such it is connected, and the exchange of goods and information has never been as prevalent. To keep up with demand, modern trends in product development are characterized by increased product complexity, shorter lifecycles and an ever rising number of product variations. These trends are presenting big challenges and demands on current manufacturing and assembly infrastructures as well as their resource management and organization. These operations are producing large amounts of new data and information regarding the procedures, tools, times, technologies etc… It can be regarded as an accumulation of knowledge for a specific company. This knowledge is the most valuable asset together with the talent they employ.

In human centric work environment, the human operator is the main decision maker. His experience, knowledge, intuition and skills directly influence the performance of the operation. But in order to reach a quality decision in an exact needed time is becoming more and more difficult. The complexity and inter - dependability of all the modules is becoming too complex. The decision maker needs help in form of amplification of his knowledge capabilities. In order to make a decision, he needs the exact information at the exact time.

One solution is referring to the integration of modern IT trends and achievements with classical industrial methods. The computing power, hardware and software have become powerful enough and at the same time, their prices have become very affordable. This combination has allowed introducing artificial intelligence ideas and concepts to help operators with the decision making and thus improving the overall efficiency and competitiveness of the company.

One such example is the introduction of the intelligent adviser module. It is connected and aware of all the module states. It is constantly collecting data and learning. Its knowledge is rising and thanks to the use of AI methods, it is able to reach conclusions and to learn. It knows when to give the exact information to the decision maker. Possibilities with such systems are endless.

Future research presents a variety of interesting topics such as machine learning functions as well as the communication between the adviser module and the operator. For the operator, an advisor module with which he can speak in a natural human language is very appealing for multiple reasons. The concept and results will be published and presented at the DAAAM conference 2015.

6. References

[1] Hobday, M., Product complexity, innovation and industrial organisation, Research Policy, Volume 26, Issue 6, February 1998, Pages 689-710, ISSN 0048-7333, http://dx.doi.org/10.1016/S0048-7333(97)00044-9.

[2] Post, P. "Smart Systems for Intelligent Manufacturing - Industry 4.0" Plenary Lecture, 25th DAAAM International Symposium, Vienna, Austria, 2014

[3] Howard, H., Levitt, R., Paulson, B., Pohl, J., and Tatum, C. (1989). Computer Integration: Reducing Fragmentation in AEC Industry, J. Comput. Civ. Eng., 3(1), 18–32.

[4] Katalinic, B., Kukushkin, I., Pryanichnikov, V., & Haskovic, D. (2014). Cloud Communication Concept for Bionic Assembly System, Procedia Engineering, Volume 69, 2014, Pages 1562-1568, ISSN 1877-7058, doi:10.1016/j.proeng.2014.03.156

[5] Goldratt, Eliyahu M., Computerized shop floor scheduling, The International Journal of Production Research 26.3 (1988): 443-455.

[6] Getty, David J., et al. "System operator response to warnings of danger: A laboratory investigation of the effects of the predictive value of a warning on human response time." Journal of Experimental Psychology: Applied 1.1 (1995): 19.

[7] Katalinic, B., Pryanichnikov, V., Ueda, K., Torims, T., Kukushkin, I., Cesarec, P., Kettler, R. (2013) Control Structure and Scheduling of a Hybrid Assembly System. - Estonian Journal of Engineering, 2013, Vol.19, Iss.1, pp.18-29., ISSN 1736-7522. Available from: doi:10.3176/eng.2013.1.03

[8] Katalinic, B., Kukushkin, I., & Haskovic, D. Bionic Assembly System Cloud: Functions, Information Flow and Behavior, 9th International Conference of DAAAM Baltic, Industrial Engineering, ISBN 978-9949-23-620-6, ISSN 2346-6138, pp 103 – 108, ed. T. Otto, Tallinn, Estonia, 2014

[9] Katalinic, B. (1997) Design Methodology of Scheduling Strategies and Scenarios of Complex Flexible Systems, Proc. 29th CIRP International Seminar on Manufacturing Systems (Ed. K. Iwata & K. Ueda), pp 179-185, Osaka University, Osaka, Japan, May 11-13, 1997

[10] Kukushkin , I. K. , Katalinic , B. , Cesarec , P. and Kettler , R. (2011) Reconfiguration in self-organizing systems. Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium "Intelligent Manufacturing & Automation: Power of Knowledge and Creativity", Editor B.[ranko] Katalinic, ISSN 1726-9679, ISBN 978-3-901509-83-4, pp 641–642, Vienna, Austria, Published by DAAAM International, Vienna, 2011

[11] Kallunki, J., Laitinen, E., Silvola, H., Impact of enterprise resource planning systems on management control systems and firm performance, International Journal of Accounting Information Systems, Volume 12, Issue 1, March 2011, Pages 20-39, ISSN 1467-0895, http://dx.doi.org/10.1016/j.accinf.2010.02.001.

[12] Umble, J. E., Haft, R., Umble, M., Enterprise resource planning: Implementation procedures and critical success factors, European Journal of Operational Research, Volume 146, Issue 2, 16 April 2003, Pages 241-257, ISSN 0377-2217, http://dx.doi.org/10.1016/S0377-2217(02)00547-7.

[13] Machizawa, M. G., Goh, C. C., & Driver, J. (2012). Human visual short-term memory precision can be varied at will when the number of retained items is low.Psychological science,23(6), 554-559.

[14] Haskovic, D., Katalinic, B., Kukushkin, I. (2014), Role of the Adviser Module in the Hybrid Assembly Subordinating Control Structure, Procedia Engineering, Volume 100, 2015, Pages 1706-1713, ISSN 1877-7058, http://dx.doi.org/10.1016/j.proeng.2015.01.546.

[15] Simon, H. A. (1960), The New Science of Management Decision, Harper & Row, New York

[16] Costello. T. W. and Zalkind, S. (1963), Psychology in Administration: A Research Orientation, Prentice-Hall, Englewood Cliffs, NJ

[17] Fishburn, P. C. (1964), Decision and Value Theory, Wiley, New York
[18] Churchman, C. W.(1968), Challenge to Reason, McGraw-Hill, New York.
[19] Holsapple, C. W. and Whinston, A. B. (1988), The Information Jungle, Dow JonesIrwin, Homewood, IL
[20] Hays, R. and Wheelwright (1984), S. Restoring Our Competitive Edge: Competing Through Manufacturing, Wiley, New York
[21] Green, C., (1969), The Application of Theorem Proving to Problem Solving, in Proceeding of the 1st International Joint Conference on Artificial Intelligence, Washington, DC., Aug, Mitre Corp. McLean, VA, pp. 219-239.
[22] Barr, A. and Feigenbaum, E. A. (1981), Eds, The Handbook of Artificial Intelligence, Addison - Wesley, Reading, MA,
[23] Rychener, M. D. (1976), Production Systems as a Programming Language for Artificial Intelligence Applications, Computer Science Dept., Carnegie-Mellon University, Pittsburgh
[24] Hendrix, G. G., Encoding Knowledge in Partitioned Networks, in N. V. FINDER, Ed., Associative Networks: Representation and Use of Knowledge by Computers, Academic Press, New York, 1979, pp. 51-92.
[25] Fikes, R. and Kehler, T, The Role of Framed-Based Representation in Reasoning, ACM, Vol. 28, No. , 1985, pp. 904-920.
[26] Fulton, S. L. and Pepe, C. O, An Introduction to Model Based Reasoning, AI Expert, January 1990, pp. 4855.
[27] Newell, A. and Simon, H. A., Human Problem Solving, Prentice-Hall, Englewood Cliffs, NJ, 1972.
[28] Lenat, D. B. and Mcdermott, J., Less than General Production System Architectures, 5th International Joint Conference on Artificial Intelligence, 1977, pp. 928-932.
[29] Cooper, T. A. and Wogrin N, Rule based Programming with OPS5, Morgan Kaufmann Publishers, California, 1988.
[30] Norman, D. A. And Rumelhart, D. E., Eds., Explorations in Cognition, W. Freeman, San Francisco, 1975.
[31] Minsky M, A Framework for Representing Knowledge, in P. WINSTON, Ed., The Psychology of Computer Vision, McGrawHill, New York, 1975, pp. 211-277.
[32] Schank. R. C. And Abelson, R. P, Scripts, Plans, Goals, and Understanding, Lawrence Erlbaum, Hillsdale, NJ, 1977.
[33] Waterman, D. A., A Guide to Expert Systems, Addison Wesley, Reading, MA, 1986.
[34] Michalski, R. S, Carbonell, J. G., And Mitchell, T. M., Machine Learning - An Artificial Intelligence Approach, Vol. II, Morgan Kaufmann Publishers, Los Altos, CA, 1986.
[35] Michalski, R. S, Carbonell, J. G., and Mitchell, T. M., Machine Learning - An Artificial Intelligence Approach, Tioga Publishing, Palo Alto, CA, 1983.
[36] Chasen, S. H., Lassiter, L. W., Johnson, K, The Evolution of Design Support for CIM. CIM Technology, February 1987.
[37] Tseng. M. M. and O'Connor, D. E., Intelligent Integrated Decision Support Systems for Manufacturing Enterprise, Proceedings 2nd International Workshop on Artificial Intelligence in Economics and Management, Singapore, Elsevier Science Publishers, Amsterdam, 1989, pp 269-277.
[38] Tseng. M. M. and O'Connor, D. E., Augmenting CIM With Intelligent Systems, in S. C. LU, Ed., Knowledge-Based Expert Systems for Manufacturing, American Society of Mechanical Engineers, New York, December 12, 1986.
[39] Barker, V. E. And O'Connor, D. E., Expert Systems for Configuration at Digital: XCON and Beyond Communication of the ACM, March 1989, pp 298-318.
[40] Shortliffe, E. H. Computer Based Medical Consultations MYCIN, Elsevier North Holland, New York, 1976.
[41] Mitchell, M. Tseng, Phaih-Lan Law and Tom Cerva, Knowledge Based Systems, Digital Equipment Corporation.
[42] Clyde W. Holsapple and Andrew B. Whinston, Decision Support Systems
[43] Wikipedia.com, n.d. Web. 18. Aug. 2015
< https://www.wikipedia.org/>