Intelligent Manufacturing Applications at Ford Motor Company

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Abstract. **There is a common misconception that the automobile industry is slow to adapt new technologies, such as Artificial Intelligence (AI), into the manufacturing sector. In reality, many of the earliest adaptations of AI were in the automotive sector where such diverse technologies as expert systems, neural networks, genetic algorithms, and fuzzy logic were among the first to be used. In this paper we will present an overview of how AI and knowledge-based technologies are currently being applied at Ford Motor Company within the manufacturing arena. Some of the applications that will be described include an AI-based approach for vehicle assembly process planning, an application of AI for ergonomics analysis and a system that utilizes machine translation to translate assembly build instructions for Ford assembly plants that do not use English as their primary language. We will also discuss how specific technologies, such as natural language processing, controlled languages, and ontologies, can be used to effectively deal with different types of knowledge, both structured and unstructured, that are prevalent in the manufacturing environment. The automobile industry is among the most competitive in the entire world, and the use of advanced technologies, is essential in the ongoing struggle to prosper in the global marketplace.**

I. INTRODUCTION

Mass-market automotive production is one of the most complex and dynamic processes that exist in industry today. The rapid change in both the business climate and the technology requires corresponding changes in the underlying product development and manufacturing processes. Therefore, it is not surprising that applications using Artificial Intelligence (AI) and Knowledge-Based (KB) technologies can be found in many facets of the automotive industry, starting from vehicle on-board intelligent functionalities and through the value chain including design, manufacturing and after-market service.

In this paper, we will discuss several types of knowledge-based applications that have been developed and deployed for manufacturing within Ford Motor Company. The goal of this paper is to discuss how AI can be successfully integrated into mainstream manufacturing processes and provide a competitive advantage. There are many other applications of AI and knowledge-based technologies within the automotive industry that lie outside the scope of this paper [1]. Our paper will discuss the following types of applications that are currently in use at Ford:

- Process Planning for Manufacturing [2]
- Ergonomic Analysis of Assembly Processes [3]
- Machine Translation of Vehicle Assembly Build Instructions [4]

This paper is organized in the following manner: Section II discusses an existing knowledge-based application that utilizes a controlled language and a knowledge-based approach to manage and plan the manufacturing processes at Ford's assembly plants. This system has been in production since the early 1990s and has demonstrated how AI can be successfully integrated into the core business processes for manufacturing. In Section III, we will discuss how a knowledge-based approach has been used to help identify potential ergonomic concerns at our assembly plants. This system has also provided an immediate and quantifiable benefit to the company in terms of reducing injury claims. In section IV, we will discuss how "machine translation" has been customized and used to translate process build instructions into other languages, such as German, Spanish, Portuguese and Dutch, for the assembly plants that use these languages. In section V, we will discuss how knowledge-based technologies and strategies are useful in other enterprise application areas, notably in the development of common ontologies and terminology management. The paper concludes with a discussion of some current work and the potential for applying knowledge-based systems for other applications within Ford.

II. AI FOR PROCESS PLANNING

The critical need to reduce cost and improve efficiency within vehicle assembly at Ford has led to the development of an AI-based system as the core for the entire manufacturing process planning system. The Global Study Process Allocations System (GSPAS) was developed to incorporate a standardized methodology and a set of common business practices for the design and assembly of vehicles to be used by all assembly plants throughout the world. GSPAS contains an embedded Artificial Intelligence (AI) component, known as the Direct Labor Management System (DLMS) that was

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developed to improve assembly process planning at Ford by achieving standardization within the vehicle process build description and provide a tool for applying standardized labor times required for vehicle assembly. In addition, DLMS provides the framework for allocating the required work among operators at the plants and builds a foundation for automated translation of the process descriptions into other languages.

The standard process-planning document used at Ford, known as a "process sheet," is the primary vehicle for conveying assembly information from the initial process planning activity to the assembly plant. A process sheet contains the detailed instructions needed to build a portion of a vehicle. A single vehicle may require thousands of process sheets to describe its assembly. A process engineer creates the process sheet utilizing a restricted subset of English known as Standard Language; it allows an engineer to write clear and concise assembly instructions that are machine-readable. These instructions are read and interpreted by the AI system to create a set of work operations and associated times that are needed by the operators at the assembly plants. Other factors, such as knowledge about ergonomics, are used by the AI system to prevent processes that will cause ergonomic problems for the operators on the assembly line from being written

The significance of using AI for manufacturing assembly lies in the following:

- Ford has developed a standardized language that is used throughout the company to describe the assembly process.
- AI allows the system to automatically read and understand these process instructions in order to calculate what work needs to be done by the operator at the assembly plant and the time needed to do this work.
- The use of AI has allowed GSPAS to check the process instructions for any potential ergonomics issues before they are sent to the assembly plants for implementation.
- AI enables the translation of work instructions into other languages to support works done at assembly plants in Europe, South America and Mexico.
- The use of AI has allowed Ford to develop a flexible and dynamic knowledge base that models the Ford manufacturing process and is easy to maintain.
- The use of AI has given the GSPAS users a tool that allows them to efficiently allocate work at the assembly plants and optimize the manufacturing layouts through a decision support system such as e-Workcell [5].

Standard Language was developed as a standard format for writing process descriptions. Prior to the introduction of Standard Language, process sheets were written in free form text, which caused major problems because of ambiguity and lack of consistency. The goal of Standard Language was to develop a clear and consistent means of communicating process build instructions between various engineering functions. The use of Standard Language has eliminated almost all ambiguity in process sheet instructions and has created a standard format for writing process sheets across the corporation.

The process sheet is the standard process-planning document used to convey assembly information from the initial process planning activity to the assembly plant. A process sheet contains the detailed instructions needed to build a portion of a vehicle as well as its associated part and tooling information. Standard Language is an example of a *Controlled Language* [6]. Controlled Languages were developed primarily to reduce the inherent complexity and ambiguity in natural language by simplifying the language and making it easier to read and understand. Such a restricted language has the advantage of being much more understandable and easier to read using natural language processing (NLP) algorithms in computer systems. A Controlled Language defines a set of explicit restrictions and constraints on the grammar, lexicon and style of the document being produced. The major aim of these constraints is to reduce the ambiguity, redundancy, size and complexity of the language that is being written. The lexicon or vocabulary in a Controlled Language is restricted by limiting the words or terms that can be used to those that are included in a glossary. Any additions or changes to the glossary must be approved before they can be added. The constraints that are put on the grammar in a Controlled Language frequently include rules limiting the length of a valid sentence, defining the structure of an approved sentence, limiting the length of noun phrases and other similar restrictions. The style of the language may be limited by not allowing passive voice, forcing the authors to place articles before certain noun phrases and restricting other types of expressions that would otherwise be legal. The use of a Controlled Language is usually enforced with computerized checking and correction that validates the syntax and vocabulary of the text before it can be released. This type of checking program will flag all instances of text that violate the Controlled Language restrictions and force the author to correct those errors before this text is approved.

The core of the GSPAS AI system is the knowledge base that utilizes a semantic network model to represent all of the automobile assembly planning information. The use of a semantic network as part of knowledge representation system is also known as *Description Logics*. A Description Logic implementation known as CLASSIC has been successfully used at AT&T to develop telecommunication equipment configurators [7]. The Ford implementation of Description Logics is based on the KL-ONE knowledge representation language [8].

The KL-ONE knowledge representation system was first developed in the late 1970's as an outgrowth of research into semantic networks. KL-ONE was selected for use on the GSPAS project because of its adaptability for many diverse applications as well as the power of the KL-ONE classification algorithm. The principal unit of information is the "concept." Each concept has a set of components or attributes that is true for each member of the set denoted by that concept. The main form of relation between concepts is called "subsumption." Subsumption is the property by which concept A subsumes concept B if, and only if, the set denoted by concept A includes the set denoted by concept B. The KL-ONE knowledge base can be described as a network of concepts with the general concepts being closer to the root of the tree and the more specific concepts being the leaves of the tree. A concept in the knowledge base inherits attributes from the nodes that subsume it. The power of the knowledge representation system lies in the classification scheme. The system will place a new concept into its appropriate place in the taxonomy by utilizing the subsumption relation on the concept's attributes.

The GSPAS AI system interprets these instructions and generates a list of detailed actions that are required to implement these instructions at the assembly plant level. These work instructions, known as “allocatable elements,” are associated with MODAPTS (MODular Arrangement of Predetermined Time Standards) codes that are used to calculate the time required to perform these actions. MODAPTS codes are widely utilized as a means of measuring the body movements that are required to perform a physical action and have been accepted as a valid work measurement system [9]. For example, the MODAPTS code for moving a small object with only a hand is M2; utilizing the arm gives a code of M3. The MODAPTS codes are then combined to describe a entire sequence of actions. MODAPTS codes are then converted into an equivalent time required to perform that action. The output from the GSPAS AI system is sent to the appropriate assembly plants where the vehicle in question is being built. Engineers at the assembly plant then allocate the job instructions among the available assembly operators. The following two figures display an example of Standard Language. Figure 1 shows a sample of a process sheet written in Standard Language. Figure 2 shows the results that are generated by the AI system for line 20 of the process sheet. The MODAPTS codes for each instruction are printed at the back of the line. Figure 3 displays the DLMS system architecture and Figure 4 shows a small portion of the knowledge base.

Process Sheet Written in Standard Language
TITLE: ASSEMBLE IMMERSION HEATER TO ENGINE
10 OBTAIN ENGINE BLOCK HEATER ASSEMBLY FROM STOCK
20 LOOSEN HEATER ASSEMBLY TURNSCREW USING POWER TOOL
30 APPLY GREASE TO RUBBER O-RING AND CORE OPENING
40 INSERT HEATER ASSEMBLY INTO RIGHT REAR CORE PLUG HOSE
50 ALIGN SCREW HEAD TO TOP OF HEATER
TOOL 20 1 P AAPTCA TSEQ RT ANGLE NUTRUNNER
TOOL 30 1 C COMM TSEQ GREASE BRUSH

Figure 1.

Resulting Work Instructions Generated by DLMS For Line 20
LOOSEN HEATER ASSEMBLY TURNSCREW USING POWER TOOL
GRASP POWER TOOL (RT ANGLE NUTRUNNER) <01M4G1>
POSITION POWER TOOL (RT ANGLE NUTRUNNER) <01M4P2>
ACTIVATE POWER TOOL (RT ANGLE NUTRUNNER) <01M1P0>
REMOVE POWER TOOL (RT ANGLE NUTRUNNER) <01M4P0>
RELEASE POWER TOOL (RT ANGLE NUTRUNNER) <01M4P0>

Figure 2.

The use of a standardized methodology and process for all vehicle programs allows us define and use a consistent approach to the manufacturing process across multiple vehicle lines and assembly plants. Another significant advantage to using a knowledge-based approach is easy maintainability. Since the original AI system has gone into production, we have made thousands of changes to the knowledge base in order to keep current with the very dynamic pace of the automotive industry. These changes include the following:

- Normal replacement and introduction of new vehicles.
- Improvements and changes to the manufacturing process.
- Introduction of new tooling and parts.
- Introduction of new technologies, such as hybrid vehicles and satellite radio.
- Changes to the external business, such as the purchase of Volvo and Land Rover.
- Changes to the terminology in Standard Language.

We have found that our approach to building and maintaining a knowledge base using "description logics" has proven to be very successful.

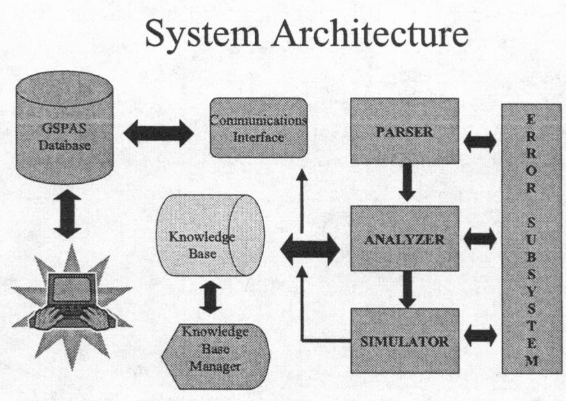

Figure 3: GSPAS AI architecture

Knowledge Base

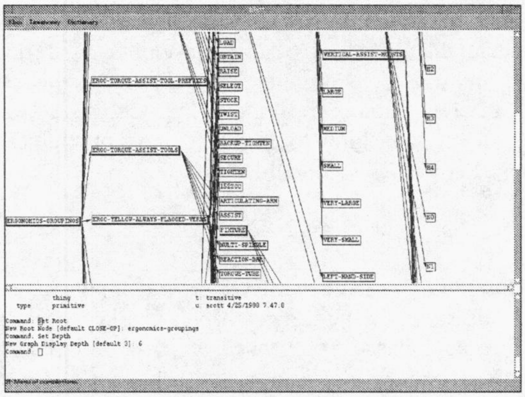

Figure 4: Portion of GSPAS AI knowledge base

III. AI FOR ERGONOMIC ANALYSIS

At the 6th Annual Applied Ergonomics Conference held in Dallas, Texas in March of 2003, the Institute of Industrial Engineers (IIE) awarded the "Ergo Cup" in Training & Education to Ford Motor Company for the GSPAS Ergonomics Application. Ford Motor Company has been utilizing an integrated process planning system since 1990 to standardize the process sheet writing, create work allocations for the plant floor and to estimate labor time accurately. This system, formerly known as the Direct Labor Management System (DLMS) is a knowledge-based system that utilizes a semantic network knowledge representation scheme. DLMS utilizes techniques from natural language processing, description logics and classification-based reasoning to generate detailed plant floor assembly instructions from high-level process descriptions. This system also provides detailed estimates of the labor content that is required from these process descriptions. Techniques, such as machine translation and evolutionary computation, were integrated into DLMS to support knowledge base maintenance and to deploy DLMS to Ford's assembly plants that do not use English as their main language.

The process sheet is the primary vehicle for conveying vehicle assembly information from the central engineering functions to the assembly plants. It contains specific information about work instructions and describes the parts and tools required for the build process. The work that is required to build the vehicle according to the process sheet instructions is then allocated among the available personnel. Work allocation requires a precise means of measuring the labor time that is needed for any particular task. The DLMS system interprets these instructions and generates a list of detailed actions that are required to implement these instructions at the assembly plant level.

Subsequently, the ergonomics engineers would manually inspect the process sheets for possible ergonomic problems. Since there may be 2000 or more process sheets for every single type of vehicle that Ford manufactures, this manual type of inspection was very labor intensive and time-consuming. An ergonomics engineer would spend upwards of two weeks in manually inspecting each process build instruction for a vehicle.

In an effort to streamline this process, we developed a system that would automate the inspection of process sheets for ergonomics concerns. This work resulted in the development of an AI system for ergonomic analysis within GSPAS that checks for two types of potential ergonomics issues: "red" and "warning." Process sheets that are flagged as "red" will not be sent to the assembly plants until those errors are corrected. Process sheets that are flagged with "warning" messages are released to the assembly plants; however, the ergonomic specialists have the opportunity to check and approve these processes.

The Ergonomics system was developed and deployed to production in April of 2002. This has already resulted in a savings of over $17,000,000 in injury cost avoidance as the high risk processes never made it to the plant floor. These calculations are based on the type of injuries prevented and the direct cost associated per injury for each type of ergonomic problem.

IV. MACHINE TRANSLATION

We have been utilizing a Machine Translation system at Ford Motor Company since 1998 within Vehicle Operations for the translation of our process assembly build instructions from English to German, Spanish, Portuguese and Dutch. This system was developed in conjunction with Systran Software Inc. and is an integral part of our worldwide process planning system for manufacturing assembly. The input to our system is a set of process build instructions that are written using a controlled language known as Standard Language. The process sheets are read by an AI system that parses the instructions and creates detailed work tasks for each step of the assembly process. These work tasks are then released to the assembly plants where specific workers are allocated for each task. In order to support the assembly of vehicles at plants where the workers do not speak English, we utilize Machine Translation (MT) technology to translate these instructions into the native language of these workers. Standard Language is a restricted subset of English and contains a limited vocabulary of about 5000 words that also include acronyms, abbreviations, proper nouns and other Ford-specific terminology. In addition, Standard Language allows the process sheet writers to embed comments within Standard Language sentences. These comments are ignored by the AI system during its processing, but have to be translated by the MT system. Standard Language also utilizes some structures that are grammatically incorrect and create problems during the MT process. Therefore, the development of a translation system for these requirements entailed considerable customization to the SYSTRAN translation engines as well as a lot of effort in building the technical glossaries to enable correct translation of Ford-specific manufacturing terminology.

Since Standard Language is constantly changing and evolving, it is necessary to keep the translation glossaries up-to-date. It is also very critical to ensure that any changes to the translation glossaries do not adversely impact any current translations. This requirement led to development of a process to maintain and improve the accuracy of the translation glossaries and includes the following components:

- The creation of a test corpus that contains a set of sample process build instructions along with the expected translations for each target language.
- The creation and use of language modeling utilities that allow us to analyze Standard Language and determine the usage frequency of terms and phrases.
- A web-based system, known as the Systran Review Manager, which allows users to maintain and add terminology to the technical glossaries.

The use of Machine Translation technology has allowed us to translate large amounts if data in a very cost-effective manner. The accuracy of the translation depends on the scope of the translation glossaries that need to be developed for the Ford-specific terminology. Our benchmarking has shown that the English-German translations are 95% accurate; other languages are less accurate, but this will improve as the translation glossaries are expanded for each language pair. We also hope to improve the accuracy of the translation programs through the use of tagging technology, where the source language text will contain XML tags with information that allows the translation engine to make better decisions about the source text.

V. KNOWLEDGE MANAGEMENT

All of the systems described above are closely coupled with other manufacturing and product development systems. These systems often use terminology that does not match the terms used within our knowledge bases. In addition, there is a lot of unstructured knowledge that contains information about "lessons learned," "best practices" and other specific knowledge that needs to be integrated into our systems. It is extremely difficult to extract the appropriate knowledge from these different data sources and present it to the user in a timely and useful fashion.

One example of knowledge integration is the need to be able to match part descriptions from the part database with the information provided in the process sheet. The process sheet is written in Standard Language and the parts database does not have this requirement. Our ergonomics processing requires us to match the part from the process sheet with the part description; if they match – we then perform some processing based on the part weight. In this case, many parts have multiple written representations, but represent one single part. We need to accommodate acronyms, synonyms, abbreviations, misspellings, misplaced punctuation and other problems inherent in natural language. The accuracy of our ergonomics analysis depends on how well we can find the appropriate part in the database and this requires more than a simple word match. Therefore, we need to build common ontologies that will allow us to match concepts from different knowledge sources and leverage this information across the entire manufacturing and product development world. Our future plans will focus on integrating unstructured knowledge from different sources, building a common ontology framework and enabling our systems to communicate and exchange knowledge among themselves.

VI. CONCLUSIONS

In this paper, we have discussed several applications within the manufacturing arena at Ford Motor Company that use AI and knowledge-based approached to solve critical business problems. The GSPAS AI system that Ford uses for process planning has been in production for over ten years. It is used throughout the assembly plants to estimate the work that is needed to build any given vehicle within Ford. We have also built a knowledge base that contains all the information needed to build a vehicle and have implemented Standard Language throughout Ford as part of the manufacturing process. Our success with the GSPAS AI system has allowed us to expand the usage of this technology into other application areas, such as Ergonomics and Machine Translation. We feel that these systems provide us a competitive advantage in the manufacturing area and show how these technologies can be utilized for other applications.

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