# BENCHMARKING THE TRANSITION TO AGILE MANUFACTURING:

# A KNOWLEDGE-BASED SYSTEMS APPROACH

H. Fred Walker, MBA
Iowa State University
Department of Industrial Education and Technology
200 I. Ed. I
Ames, IA 50011
(515) 294-2036
FAX (515) 294-1123

Eugene Wallingford, Ph.D.
University of Northern Iowa
Department of Computer Science
331 Wright Hall
Cedar Falls, IA 50614
(319) 273-5919
FAX (319) 273-2546

Ronald Meier, Ph.D.
Iowa State University
Department of Industrial Education and Technology
114 I. Ed. II
Ames, IA 50011
(515) 294-8040
FAX (515) 294-1123

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## ABSTRACT

AM is a rapidly developing methodology of competitive revitalization for the manufacturing sector of the American economy. AM seeks to integrate and synthesize many concepts and theories which have, when implemented in virtual isolation, provided some promise of competitive advantage. A significant dilemma for AM, however, is that few tangible tools have been provided to manufacturers that would help to manage the flow of information necessary during the transition to agility. The role of artificial intelligence (AI) in manufacturing is a subject of critical importance to efficient and effective information management. The subset of AI with the greatest potential to make a significant contribution to the management of information is knowledge-based systems (KBS), the focal point of the research discussed in this paper. The KBS described here, AM-CHECK, aims to provide guidance as enterprises make the transition to agile manufacturing. AM-CHECK uses an innovative integration of two problem-solving methodologies, structured matching and candidate evaluation, that enables the system to process both qualitative and quantitative data.

# BENCHMARKING THE TRANSITION TO AGILE MANUFACTURING: A KNOWLEDGE-BASED SYSTEMS APPROACH

Of the sub-components comprising artificial intelligence (AI), knowledge-based systems (KBS) has been recognized throughout current literature as a technology with the potential to provide invaluable advancements in information management. One such advancement in information management for manufacturing is being facilitated in a KBS called AM-CHECK, currently under development for benchmarking the transition to Agile Manufacturing (AM). The system is being developed through a joint research effort between Iowa State University and the University of Northern Iowa.

AM-CHECK will help demonstrate a vital role for AI in manufacturing. This role will be to provide a source of expert information to remote locations. The system relies on the integration of two distinct, yet compatible, models of problem solving enabling quantitative as well as qualitative evaluation through a technique known as *structured matching*. Structured matching represents an application of AI theory to information management problems in real-world, operational settings. Through structured matching and similar techniques, the application of AI to new areas in manufacturing, such as benchmarking, is a possibility with great promise.

This paper will briefly identify and define the system domain of AM, discuss the need for systems with the capability of quantitative and qualitative evaluation, provide a traditional system profile, delineate intended benefits, and address implications for future research.

## AGILE MANUFACTURING

AM is a manufacturing competitiveness revitalization strategy designed to counteract nearly two decades of competitive decline for American manufacturers. Decline occurred as large and unresponsive American mass-producers experienced market share erosion to foreign-based “lean” manufacturers. These smaller, more flexible, and more responsive manufacturers took decisive control of global markets largely due to their ability to overcome inefficiencies associated with inflexible American-style mass-production. Lean manufacturers facilitated the shift in market dominance by systematically reevaluating and redefining the importance of all inputs to manufacturing processes [1].

American response to global market share erosion was the unsuccessful exploitation of flexible but stand-alone technologies such as computer-numeric-control machine tools, robotics, flexible manufacturing systems, computer-aided-design/drafting, and computer-integrated-manufacturing. Since 1991, however, the Agile Manufacturing Enterprise Forum (AMEF) has begun the process of revitalizing American manufacturing, as requested by the United States Congress.

Origins of AM are contained in the 1991 defense authorization bill that mandated that a National Defense Manufacturing Plan be developed and submitted to Congress for implementation by the year 2006 [2]. The plan was intended to redefine the importance of operational elements previously not considered vital to manufacturing: (1) business environments, (2) information communication, (3) multi-organizational teams, (4) flexibility, (5) concurrency, (6) environmental enhancement, (7) human resource management, (8) subcontractor/supplier support, and (9) technology deployment [3]. To integrate these nine organizational elements, AM requires an infrastructure consisting of three major components:

- a nation-wide data network at the factory level,
- flexible and responsive manufacturing facilities, and
- government cooperation.

To overcome reliance on stand-alone technologies and promote modular product designs which evolve with the needs of consumers, the industry-led AMEF took charge of plan development. The purpose of the forum was to develop a methodology for creating reprogrammable, reconfigurable, continuously changeable production systems to guide manufacturing into the 21st century. Unfortunately however, no tangible tools utilizing flexible automation or innovative information management technologies, such as benchmarking and knowledge-based systems, have yet been delivered to American manufacturers.

This paper describes a tool that is intended as a first step in this direction. The tool, AM-CHECK, combines two technologies identified by the AMEF as vital: *benchmarking* procedures and a subset of artificial intelligence known as *knowledge-based systems*. The goal underlying tools such as AM-CHECK is that they can serve as invaluable sources of standardized, readily-available expertise to guide the transition to agility not only for large corporations but also for small and medium-sized manufacturers. AM-CHECK will initially operate as a stand-alone tool but will later be integrated with a larger suite of systems, in particular with more conventional information systems technology.

## THE NEED FOR QUANTITATIVE AND QUALITATIVE KBSs

Building knowledge-based tools for use in a particular application domain requires some degree of clarity in the knowledge of that domain. Given the relative youth of the agile manufacturing movement, several unresolved issues complicate the design and development of knowledge-based tools for AM. Among these issues are:

- How can AM be defined and differentiated from other manufacturing competitiveness strategies?
- What benchmarks would be most useful for assessing agility?
- How can knowledge-based systems be used to deliver a tool that combines mass-lean-agile characteristics and standardized AM benchmarks?
- How would such a tool be tested and validated?
- How will such a tool be disseminated?

Given these crucial issues, our approach is specifically focused on identifying and correcting underlying problems, building upon current AI research, and meeting the needs of practicing manufacturers. Systems such as AM-CHECK are needed to resolve multi-faceted, long-term and short-term tool availability issues utilizing existing industrial and academic resources.

Meeting the needs for AM transitional tools will contribute to revitalizing the competitive position of American manufacturers. The KBS, however, will also enable manufacturers to:

- communicate in a common language about standardized issues, needs, characteristics, and benchmarks, and
- identify and correct deficiencies hindering competitiveness and profitability.

To capture these benefits, the following objectives have been developed to answer issue-related questions that business, industry, and government have identified as crucial for improvement of the American manufacturing economy.

- Identify commonalities between lean production and AM.
- Identify mass-production, lean production, and AM characteristics.
- Create a mass production—lean production—AM multi-dimensional scale for organizational self-evaluation.
- Establish measurements for AM benchmarks.
- Develop a standardized set of AM benchmarks.
- Construct a KBS specifically designed for benchmarking agility. This system is being built using SM, a tool that facilitates development of assessment and evaluation systems.
- Pilot test, debug, and document the KBS.
- Create a plan for disseminating the system.
- Disseminate the system.

## SYSTEM PROFILE

"Intelligent" benchmarks that indicate relative position on a multi-dimensional scale of mass production, lean production, and agile manufacturing meet a critical AMEF need. Further, objective comparisons between individual organizations and benchmarking standards are necessary [4] and comprise an integral part of the system. Collectively, these cross-functional benchmarks provide feedback on how American manufacturers may modify current operations or organizational structure to gain competitive advantage. To this end, AM-CHECK is being developed by an inter-disciplinary team of researchers at Iowa State University and the University of Northern Iowa.

Two problems facing American manufacturing are (a) a lack of available expertise to identify sources of competitive advantage and (b) lack of a standard to which manufacturers can compare themselves to ascertain their level of competitiveness. The task of AM-CHECK is to <u>evaluate</u> an enterprise's current organizational structure and manufacturing processes and to <u>select</u> appropriate strategies for modifying structures and processes based on identified weaknesses.

AM-CHECK addresses tasks by carefully applying knowledge of manufacturing and its constituent technologies, leading the system user through a directed dialogue of questions. The questions represent expert knowledge encoded in the system as standards. In response to these directed questions, the system accepts qualitative input in the form of Likert scale-type responses (e.g., strongly agree, agree, disagree, strongly disagree) from a menu system via a graphical interface. Output of the system is an "expert" assessment of a firm's competitiveness in relation to the standards encoded in the system and a set of recommendations regarding appropriate strategies to attain competitive advantage.

### Conceptual Decomposition of the Problem

One of the central notions underlying the earliest work in knowledge-based systems was that a general problem-solving algorithm was sufficient for solving complex problems. In this approach, domain knowledge could be described with a set of IF-THEN rules, independent of any particular high-level problem-solving algorithm. This knowledge could then be provided to an inference engine as "input data" for solving a problem in the domain. This approach encountered two primary difficulties as a result of its basic assumptions. First, system developers found that they had to the design a problem-solving method tailored to each task at hand. Second, rule-based approaches did not support the level of abstraction necessary for analyzing the problem and designing a rule-based solution.

Two intuitions grew out of these experiences: Certain knowledge and methods are common to a particular task (e.g., selection) across many different domains, and the knowledge and methods necessary for different tasks will differ even within the same domain. These intuitions gave rise to a new family of approaches to problem solving, termed *task-specific* approaches. AM-CHECK builds on the task-specific approach known as Generic Tasks (GT), developed by Chandrasekaran and his colleagues [5].

The primary assumption of the GT approach is that knowledge takes different forms depending on its intended use [6]. Following the GT view, a problem is analyzed according to the methods associated with solving it, where each method can be specified by (a) the forms of knowledge and inference necessary to apply the method and (b) the sub-problems that must be solved to carry it out. The claim of the GT approach is that there exist a number of ubiquitous combinations of method, knowledge structure, and inference structure — termed generic tasks — for a variety of problem solving tasks in a variety of domains. The totality of domain knowledge for solving a given problem is viewed as a composition of generic task "agents" that interact based upon their functions and information needs. Among the generic tasks identified thus far are hierarchical classification, routine design, functional modeling, and structured matching (SM).

The generic task most appropriate for benchmarking in agile manufacturing is structured matching [7]. SM follows, in large part, longstanding results on data abstraction in artificial intelligence. A structured matcher can be viewed as a structured knowledge base containing patterns of experience-based information for making a decision. The basic idea of structured matching is that partitions of data can be used as a central component of efficient decision making. For example, in determining whether or not a manufacturer is highly agile, a manager will generally analyze those features of the firm that affect its agility, such as its business environment, its flexibility, the concurrency of its design processes, and so on. Patterns dealing with business environment would be placed in one partition, or simple matcher, and patterns relating to flexibility would reside in a second simple matcher. Thus, the problem solver's knowledge is partitioned into one or more simple matchers, each of which can be evaluated based on the patterns it contains.

The simple matcher is the basic unit of structured matching. In order for a high-level decision to be made, a structured matcher must be able to evaluate its lower-level matchers and merge the results of these evaluations into an overall decision. Structured matching accomplishes this by reporting the values of its lower-level matchers, those dealing with direct observations, to higher-level knowledge groups that correspond to more abstract partitions of knowledge. A higher-level matcher takes these values, which are "abstract" in the sense that they represent the degree of fit in terms of a small set of discrete values, and composes an aggregate evaluation of all the simple matchers reporting to it. As a result, structured matching employs a hierarchy of simple matchers to decompose and perform its task. This is the central motivation for SM, as well as a key feature that distinguishes AM-CHECK from traditional rule-based programming.

## System Structure and Operation

The section describes the initial prototype version of AM-CHECK, a working prototype system constructed at the University of Northern Iowa's Intelligent Systems Laboratory during the spring of 1993. Operationally, AM-CHECK enters into a dialogue with a user, who responds to questions via a graphical interface. To facilitate shortened learning time for system users, a menu system format is used during the dialogue. System users answer questions related to one or more of the organizational elements, and system responses indicate a position on a mass-lean-agile multi-dimensional scale and provide appropriate suggestions for deficiency correction. Future versions of the KBS will also provide case-based objective comparisons to other relevant American companies.

The current structure of AM-CHECK consists in a five-level hierarchy, which offers the ability to organize and represent the domain knowledge in its most natural and accepted form. Figure 1 illustrates each of the top two levels of factors in AM-CHECK. The top node in the hierarchy is termed *agility*, to denote that it makes the overall decision regarding the enterprise's agility. The second level consists of matchers corresponding to factors previously identified by the AMEF as central facets of agility.

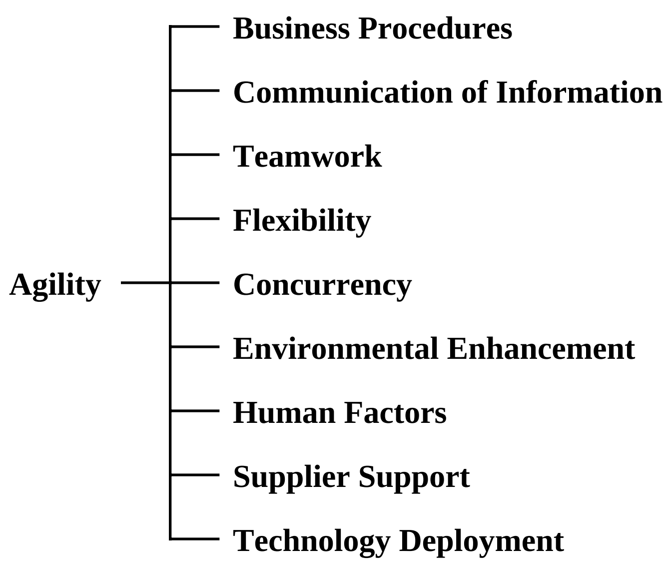


**Figure 1**: The Top Levels of the Matcher Hierarchy

Each node in this hierarchy contains a table of pattern-matching IF-THEN rules. These rules aggregate the values returned by the matchers at the next lower level. Consider the matcher *agility*. While lower-level matchers consider individual data about the enterprise (e.g., its use of workstations in design), *agility* will consider such abstract notions as teamwork, flexibility, and supplier support. The final decision regarding the enterprise's agility is made not on the basis of the numerous individual data, which are large in number and often in conflict, but rather on the basis of how they as a whole are deemed to affect the firm's agility. In the initial prototype of AM-CHECK, a demonstration-of-concept system, only flexibility is considered as a factor in assessing agility.

Figure 2 shows the table of rules employed by the agility matcher in this scenario. These rules are evaluated in order from top to bottom until a rule "fires." A rule fires by satisfying the conditions set on the left-hand side of the rule. The matcher then returns the qualitative value associated with the rule that fires. The value returned when a rule fires reflects the extent to which domain knowledge content is matched with system user input.

The matcher *flexibility* operates in a similar fashion, returning a qualitative rating for the enterprise's level of flexibility. To make this decision, the matcher first requests that decisions be made about key factors affecting flexibility. Figure 3 depicts the sub-decisions considered by AM-CHECK in determining the level of flexibility. The table contained by *flexibility* in the prototype consists of nine rules that aggregate the values returned for these key factors. These factors relate to the firm's use of hardware and software

| **If *Flexibility* returns a value of:** | **... then *Agility* returns a value of:** |
|---|---|
| **highly flexible** | **highly agile** |
| **at least somewhat flexible** | **somewhat agile** |
| **unknown** | **unknown** |
| **no more than somewhat inflexible** | **somewhat rigid** |
| **highly inflexible** | **highly rigid** |

**Figure 2:** The Pattern-Matching Rules for *Agility*

technologies, with additional consideration of the human-technology interface.

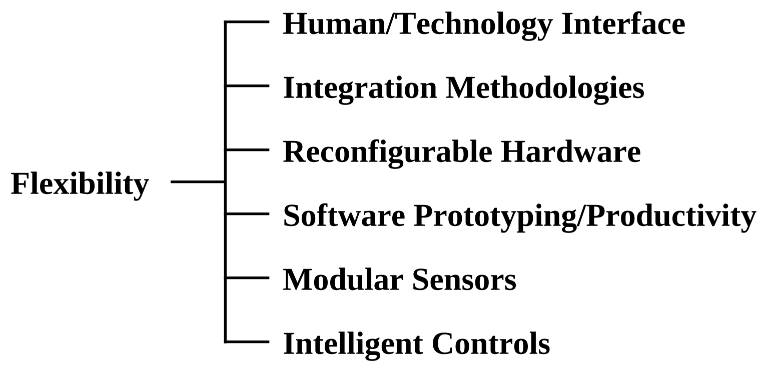


**Figure 3:** Another Portion of the Matcher Hierarchy

Figure 4 gives the nine pattern-matching rules used by the flexibility matcher. Again, since the initial prototype of AM-CHECK is only a demonstration-of-concept system, the rules in this table actively consider only two of the sub-decisions, those relating to reconfigurable hardware and the human-technology interface. Future versions of AM-CHECK will consider all six of the sub-decisions outlined in Figure 3. Notice that consideration of multiple factors necessitates the use of more complex patterns in the rules. In order for a rule in *flexibility*'s table to fire, both conditions on the rule must be satisfied. This form of complexity makes writing large tables of rules a difficult task. Generally, any table with more than ten rules should be decomposed into two or more smaller tables that reflect other factors in the decision making process. (This guideline is consistent with the notion that human problem solvers tend to decompose complex tasks into smaller, more manageable problems using intermediate abstractions.)

| If *Reconfigurable Hardware* returns a value of: | and *Human-Technology Interface* returns a value of: | ... then *Flexibility* returns a value of: |
|---|---|---|
| mostly reconfigurable | highly productive | highly flexible |
| at least reconfigurable | at least productive | somewhat flexible |
| at least reconfigurable | (anything) | somewhat flexible |
| unknown | unknown | unknown |
| no more than rigid | no better than unproductive | somewhat inflexible |
| no more than rigid | (anything) | somewhat inflexible |
| (anything) | no better than unproductive | somewhat inflexible |
| no more than rigid | (anything) | somewhat inflexible |
| worse than rigid | (anything) | highly inflexible |

**Figure 4:** The Pattern-Matching Rules for *Flexibility*

Each subsequent level in the hierarchy is evaluated in the manner described above, following a hierarchy of simple matchers. After evaluation of all necessary factors, a qualitative value denoting the firm's overall position on the mass-lean-agile continuum is returned to the system user. Later versions of AM-CHECK will also provide recommendations for actions that the firm can take to increase its agility, based on weaknesses identified in the course of benchmarking. By taking the appropriate recommended actions, a firm can hope to increase its level of agility, which provides numerous benefits based on increased competitive advantage.

## A QUANTITATIVE EXTENSION TO STRUCTURED MATCHING

In the course of building the initial prototype of AM-CHECK, the use of structured matching introduced some difficulties. SM requires that knowledge be in a highly "compiled" form, that is, that it be structured efficiently for use based on experience gained from solving the problem repeatedly in practice. For many tasks and domains, such as mechanical troubleshooting, this requirement is reasonable, since human practitioners have much experience performing the tasks under real-world conditions. However, the field of agile manufacturing is young and, at this point, knowledge of agility and its constituent features is not well understood.

Though one can speak in general terms about agility and its attendant capabilities, little formal analysis has yet been completed that would allow these concepts to be incorporated into a computer-based benchmarking system. In applications such as AM, where such knowledge is not readily available, development of a KBS using structured matching can be significantly hindered. Satisfactory completion of AM-CHECK requires an extension to the theory underlying SM to incorporate sources of knowledge which are not thoroughly compiled.

One type of structured pattern matching not currently available within SM's family of methods has been identified by Mitri [8]. This form of matching, termed candidate evaluation, requires that a pattern matcher's value be based on a *weighted sum* of the numeric values of its constituent factors, where these factors are sub-decisions or stipulated facts. These numeric values denote particular positions on a normalized scale of 0.0 to 1.0. The linear combinations of these values can then be converted to qualitative ratings using a pre-defined scale mapping numeric values to qualitative values. This technique can be distinguished from structured matching in that candidate evaluation uses numeric values and thresholding rather than directly computing and combining qualitative values.

| **Subdecision** | **Weight** |
|---|---|
| **Software Productivity** | **0.15** |
| **Intelligent Controls** | **0.15** |
| **Reconfigurable Hardware** | **0.20** |
| **Human-Technology Interface** | **0.20** |
| **Modular Sensors** | **0.15** |
| **Integration Methodologies** | **0.15** |

| **Rating** | **Threshold** |
|---|---|
| **highly flexible** | **0.75** |
| **somewhat flexible** | **0.55** |
| **unknown** | **0.45** |
| **somewhat inflexible** | **0.25** |
| **highly inflexible** | **0.00** |

**Figure 5:**
A Flexibility Matcher in Candidate Evaluation

Figure 5 demonstrates the major concepts of candidate evaluation by giving a sample node for flexibility in a candidate evaluation hierarchy. Instead of a table of pattern-matching rules, each "matcher" in such a hierarchy contains (1) a set of weights for combining the values returned by its sub-decisions and (2) a set of qualitative ratings and corresponding numeric thresholds for earning each rating. The flexibility node in Figure 5 computes its numeric value by applying the weights associated with each sub-decision to the values returned by those nodes. To compute its qualitative value, the node chooses the lowest threshold satisfied by the numeric value and returns the rating associated with that threshold. Figure 6 provides a sample computation for *flexibility*. Based on the computation shown, flexibility returns a numeric value of 0.61 and a qualitative rating of "somewhat flexible."

| **Sub-decision** | **Value** | **Weight** |
|---|---|---|
| **Software Productivity** | **0.60** | **0.15** |
| **Intelligent Controls** | **0.45** | **0.15** |
| **Reconfigurable Hardware** | **0.80** | **0.20** |
| **Human-Technology Interface** | **0.30** | **0.20** |
| **Modular Sensors** | **0.80** | **0.15** |
| **Integration Methodologies** | **0.75** | **0.15** |

**Flexibility =**

$$0.15 * 0.60 + 0.15 * 0.45 + 0.20 * 0.80 + 0.20 * 0.30 + 0.15 * 0.80 + 0.15 * 0.75 = 0.61$$

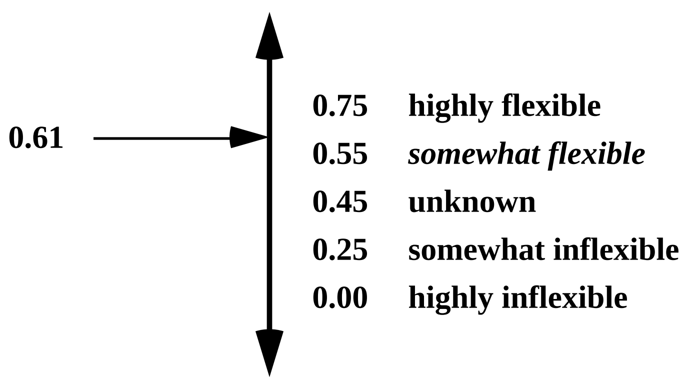


**Figure 6:** Thresholding in Candidate Evaluation

This proposed extension to structured matching has some foundation in existing SM theory. The idea of computing a matcher's value by summing the values of its sub-decisions has been discussed by Bylander, Johnson, and Goel [7] under the term "sum matching." Their work, however, does not incorporate weighted sums or mappings between quantitative and qualitative values, as does the candidate evaluation work of Mitri.

The goal of this project, then, is to integrate Mitri's candidate evaluation technique into the family of structured matching methods. The motivation for this integration lies in the nature of those target domains in which neither SM nor candidate evaluation alone can adequately model problem solving knowledge in the domain. Future versions of AM-CHECK will contribute to the body of AI applications an operational knowledge-based system that makes hierarchical decisions using both quantitative and qualitative ratings.

## BENEFITS

Given the need for competitive revitalization, the principles of agile manufacturing intend to provide the following benefits in both the short- and long-term:

- improved production technologies,
- enhanced managerial techniques, and
- a more knowledgeable work force.

As a first step toward attaining these benefits, the AM-CHECK system is expected to offer the following features:

- identification of unrealized sources of competitive advantage through standardization of procedures,
- providing expertise from a clearinghouse where it may have been unavailable due to remoteness or not being connected to the information network, and
- streamlining the flow of information to provide the real-time means necessary for manufacturers to interact and interface as flexible and responsive virtual partners.

The benefits offered by this research project are clearly and concisely directed at providing an innovative cross-functional tool to aid in the transition to AM. The alternative to not conducting this type of research is unappealing, as Weimer [9] noted: “...if American business and American people don’t respond to the foreign challenge in manufacturing in some very creative ways, we will continue to decline in terms of wealth and power.”

One goal of the researchers developing AM-CHECK is that the long-term results of this project be combined with other efforts related to agile manufacturing to provide a comprehensive and supporting infrastructure to guide American manufacturing into the 21st century.

## IMPLICATIONS FOR FUTURE RESEARCH

Future investigation of this project will proceed in two primary directions. The first involves the further formalization of knowledge in the area of agile manufacturing. In line with ongoing efforts mandated by the Agile Manufacturing Enterprise Forum, research will investigate the factors that constitute agility, from abstract notions such as “flexibility” down to operationalize data that characterize manufacturing enterprises. This work will seek to outline the relevant factors and come to a more formal understanding of how these factors interact to make a firm “agile.” Finally, this work will also have to identify and categorize the steps a firm can take to become more agile in the face of particular weaknesses in the firm’s structure and processes.

The second direction of this work involves expanding the modeling tools needed for the construction of an adequate benchmarking system for the transition to agility. Other researchers, both in and out of computer science, have delved into the notion of so-called *compensatory reasoning*, in which weighted sums of factor values are combined to arrive at solution values in hierarchical decision making. In AM-CHECK, this project seeks to fully integrate Mitri’s work on knowledge-based compensatory reasoning systems with structured matching to provide an ability to do matching with weighted sums and thresholds.

Ultimately, the goal is to create a modeling tool that supports hierarchies of matchers making decisions in the most suitable way for the factor at hand. This will include having threshold matchers interacting directly with standard simple matchers, and vice versa, wherever appropriate. Such a tool will enable the development of knowledge-based systems that integrate qualitative and quantitative decision making, broadening the range of applications for which structured matching solutions can be constructed. The true implications for future research in this area lie in developing systems that fully utilize the capabilities of the full problem solving methodology described here.

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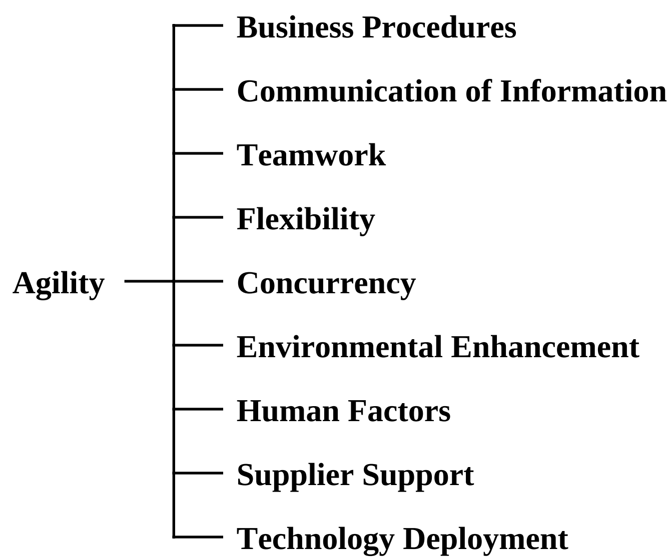


**Figure 1**:  The Top Levels of the Matcher Hierarchy

| **If *Flexibility* returns a value of:** | **... then *Agility* returns a value of:** |
|---|---|
| **highly flexible** | **highly agile** |
| **at least somewhat flexible** | **somewhat agile** |
| **unknown** | **unknown** |
| **no more than somewhat inflexible** | **somewhat rigid** |
| **highly inflexible** | **highly rigid** |

**Figure 2:** The Pattern-Matching Rules for *Agility*

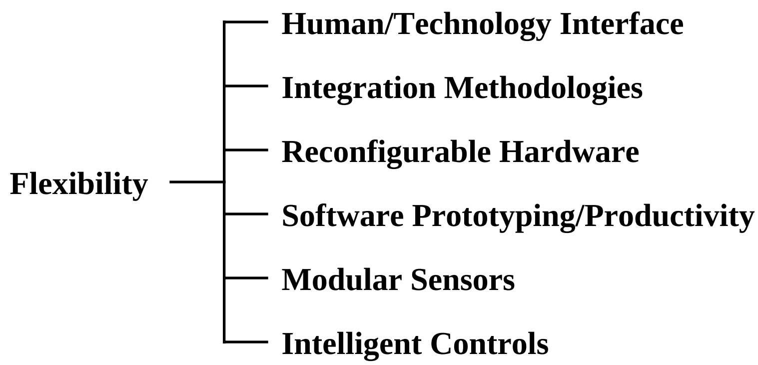


**Figure 3:** Another Portion of the Matcher Hierarchy

| If *Reconfigurable Hardware* returns a value of: | and *Human-Technology Interface* returns a value of: | ... then *Flexibility* returns a value of: |
|---|---|---|
| mostly reconfigurable | highly productive | highly flexible |
| at least reconfigurable | at least productive | somewhat flexible |
| at least reconfigurable | (anything) | somewhat flexible |
| unknown | unknown | unknown |
| no more than rigid | no better than unproductive | somewhat inflexible |
| no more than rigid | (anything) | somewhat inflexible |
| (anything) | no better than unproductive | somewhat inflexible |
| no more than rigid | (anything) | somewhat inflexible |
| worse than rigid | (anything) | highly inflexible |

**Figure 4:** The Pattern-Matching Rules for *Flexibility*

| **Subdecision** | **Weight** |
|---|---|
| **Software Productivity** | **0.15** |
| **Intelligent Controls** | **0.15** |
| **Reconfigurable Hardware** | **0.20** |
| **Human-Technology Interface** | **0.20** |
| **Modular Sensors** | **0.15** |
| **Integration Methodologies** | **0.15** |

| **Rating** | **Threshold** |
|---|---|
| **highly flexible** | **0.75** |
| **somewhat flexible** | **0.55** |
| **unknown** | **0.45** |
| **somewhat inflexible** | **0.25** |
| **highly inflexible** | **0.00** |

**Figure 5:**
A Flexibility Matcher in Candidate Evaluation

| Sub-decision | Value | Weight |
|---|---|---|
| **Software Productivity** | **0.60** | **0.15** |
| **Intelligent Controls** | **0.45** | **0.15** |
| **Reconfigurable Hardware** | **0.80** | **0.20** |
| **Human-Technology Interface** | **0.30** | **0.20** |
| **Modular Sensors** | **0.80** | **0.15** |
| **Integration Methodologies** | **0.75** | **0.15** |

**Flexibility =**

$$0.15 * 0.60 + 0.15 * 0.45 + 0.20 * 0.80 + 0.20 * 0.30 + 0.15 * 0.80 + 0.15 * 0.75 = 0.61$$

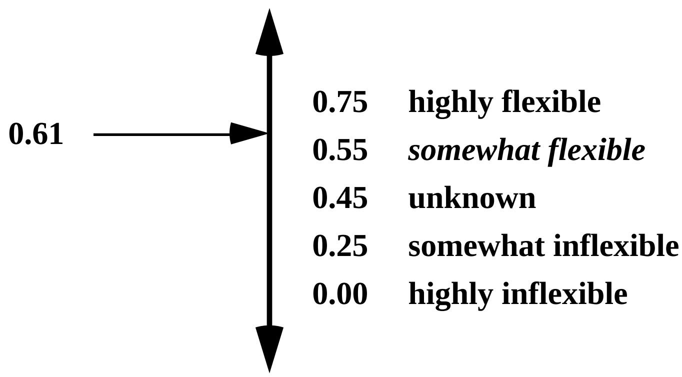


**Figure 6:** Thresholding in Candidate Evaluation