

# Multi Dimension Quality Model of MAS

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## Abstract

*Advances in networking technology have revitalized agent technology for engineering complex distributed software systems. Nowadays, the agent technology has been applied in a wide range of application domains, including e-commerce, human computer interfaces, telecommunications and concurrent programming. A lot of research has been done on design and development of Multi-agent systems (MAS) but quality in MAS has not yet received much attention. Large-scale MAS based software development will require support for a diverse range of quality dimensions and respective attributes. This paper defines quality model of MAS that addresses various dimensions of quality and proposes a method to evaluate the quality, which is based on quality factor-criteria relationship.*

**Keywords:** Multi-agent systems, Dimension, Factor, Criteria, Evaluation, Quality Prism

## 1. Introduction

In software engineering community there is an increasing effort of revising and restructuring software projects in terms of Multi-agent systems (MAS). Multi-agent systems pose challenges for software engineers, as the quality in MAS is not straightforward. However, both researchers and practitioners are lacking a comprehensive framework that would help them evaluate the quality of MAS. And there is a pressing need for software-engineering techniques that allow their quality to be effectively managed.

Multi-agent systems (MAS) consist of an environment populated with a set of autonomous entities (agents) that cooperate to solve a complex problem in decentralized way. Software agents are autonomous program units that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems and can move throughout a network of agent aware computers [3]. Agents are characterized as autonomous, goal-oriented, situation aware and proactive as well as reactive. MAS models problems in terms of autonomous interacting component-agents, which is proving to be a more natural way of representing task allocation, team planning, user preferences, open environments, and so on. Multi-agent systems has been applied in a variety of domains, including aircraft maintenance, wireless collaboration and communications, financial portfolio management, supply chain management etc. In [13], the application of multi-agent systems to monitor complex chemical processes has been presented. An application of MAS to a service mobile manipulator robot that interacts with a human during an object delivery and hand-over task has been presented in [14]. Mahamat Guiagoussou, Said Soulhi presents the implementation of a maintenance application for cellular switching system using the Multi-agent paradigm [15].

A lot of research has been done on design and development of Multi-agent systems (MAS) but quality in MAS has not yet received much attention. Large-scale MAS based software development will require support for a diverse range of quality dimensions and respective attributes. We found a little guidance in literature on what constitutes a “complete quality” in MAS. Behrouz Homayoun Far [2] defines Knowledgeability and Complexity issues in MAS. In [3], a method for measurement of quality of Java agents has been presented using extreme programming, which depends only on code. Behrouz Homayoun Far and Romi Satria Wahono [6] have defined mechanisms for decision-making by software agents in uncertain environments. In [12], the role of trust in multi-agent systems has been examined. In [16], an approach for fault-tolerance of multi-agent systems has been discussed. In order to fully investigate the operational context of quality, it is necessary to examine all facets and perspectives of the implementation. This research is an attempt to determine the factors that contribute to the quality in MAS.

Quality in software systems is defined as the degree to which a system, a component or process conforms to specified requirement [4] or fitness for use. ISO Standard 8402 defines quality as; “The totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs”. A quality based product results in better user satisfaction. Conventional software quality models such as McCall’s [5], and ISO 9126

(based on 6 factors: functionality, reliability, usability, maintainability, efficiency and portability) addresses quality of software in terms of factors and criteria.

McCall's product quality model captures the characteristic of software for defining quality [5]. And software is defined as a set of instructions (programs), data structures and documents that describe the operation of programs whereas software agent is a computer program that is capable of autonomous actions in pursuit of a specific goal [17]. The autonomy characteristic of a software agent distinguishes it from general software program. So we need an extended quality model that addresses the characteristics of agents to define quality in MAS. Our quality model is an effort in that direction.

The paper is organized as follows: Section 2 defines MAS Quality Model, which is based on quality in MAS from various dimensions. Section 3 gives relationship of quality factors and criteria in MAS. Section 4 describes MAS quality measurement from viewpoint of stakeholders. Section 5 concludes the paper.

## 2.MAS Quality Model

Quality in MAS may be defined as achieving high levels of Technical, Visualization, Domain, Social, Dynamic, and Supportive excellence. In a quantitative sense, to evaluate a system is to measure its all dimensions in terms of well-defined factors and factors in terms of criteria and at the lowest level are the metrics, which measure the criteria. In MAS, quality can be examined from various dimensions such as:

- ◆ **Technical Excellence**
- ◆ **Visualization Excellence**
- ◆ **Domain Excellence**
- ◆ **Social Excellence**
- ◆ **Dynamic Excellence**
- ◆ **Supportive Excellence**

The dimensions of quality in MAS and the respective key attributes are discussed as follows:

**2.1 Technical Excellence:** This characterizes the MAS with respect to efficiency and effectiveness in performing the task and achieving the goals. It entails the following key attributes:

- *Confidence:* It is the extent of consistency, reliability, uncertainty, and exception handling that would be supported by MAS.
- *Realism:* The extent to which the performance of MAS matches with that of a human agent in terms of problem solving and achievement of goals.
- *Efficiency:* It characterizes the MAS in terms of turn around time and response time.
- *Reputation:* The overall improvement in the effectiveness and credibility of the organization brought about by the MAS.
- *Intelligence:* It is ability of MAS to react, to take initiatives for achievement of goals, to take decisions and to make use of knowledge from its knowledgebase..
- *Cost Effective:* The extent to which MAS is viable in terms of cost-benefit analysis.

**2.2 Visualization Excellence:** This perceives the MAS with respect to the utilization and appearance of system by users. The key attributes of this perception are as follows:

- *Look & Feel:* It addresses the level of clarity and overall appearance of the multi-agent system.
- *Learnability:* The ease with which user can learn the system and eventually utilizes the system.
- *Interactivity:* The extent to which the user is comfortable with the system's dialogue.
- *Educative:* It is the degree to which user gets informative as a consequence of utilizing the system.
- *Documentation:* The extent to which online help and reference manuals are available to assist users in using the system.
- *Acceptability:* It is the extent to which MAS is acceptable to user community and is usable by them.

**2.3 Domain Excellence:** Knowledge is prerequisite to wisdom and is defined as the ability to use the information. Knowledge is an integral part of MAS paradigm. Agents must be knowledgeable in their area of expertise to interact and work proactively. This characterizes the MAS as follows:

- *Knowledgeability:* It is degree to which MAS acquires the knowledge from its environment, peer agents and its users and reasons about its goals.
- *Exhaustiveness:* The level of richness and thoroughness of the knowledgebase.
- *Persistency:* It is the ability of MAS to retain its state and the knowledge.
- *Codability:* The extent to which the knowledge representation scheme that is used to code and modify the knowledgebase is flexible and powerful.
- *Precision:* The level of accuracy of the knowledge gained from the MAS.

- *Sensing*: It is the ability of the system to reflect the changes in the environment to its knowledgebase.
- *Specificity*: The level of content relevance, completeness and accuracy achieved by MAS in achieving the goals.

**2.4 Social Excellence:** Multi-agent systems harness cooperation and coordination among a collection of agents to perform meaningful work. These interactive agents form social structures that can resemble a society. The characteristics of this dimension are as follows:

- *Collaboration*: This is the extent to which agents in MAS communicate, interact and exchange messages to negotiate or share the information with other agents. They perform a task in coordination with some other agents.
- *Autonomous*: It is the ability of agents in MAS to proactively initiate activities according to its goals, act on its user's behalf, and exercises control over its own actions.
- *Competitive*: It is the extent to which agents make decisions in competitive environments under uncertainty, predict environment's parameters, predict other agent's future moves, and successfully explain self and other agent's actions.

**2.5 Dynamism Excellence:** It is defined as the ability to adapt to the changing situations. Agents are by nature dynamic entities. Dynamism highlights the following characteristics of MAS:

- *Agility*: It is the ability of MAS to react quickly to the changing environment.
- *Robustness*: It is the effort required in assigning tasks to another agent in MAS if one agent fails or gets overloaded.
- *Flexibility*: It is the degree to which MAS dynamically chooses which action to invoke and what sequence in response to change in environment.

**2.6 Supportive Excellence:** This defines the level of support for increasing the scope and level of problem solving of MAS. It addresses the following key attributes:

- *Customization*: This is the effort required to increase the services of agents in MAS.
- *Compatibility*: It is the degree to which the system complements other existing agent systems and technology in the organization.
- *Reusability*: It is the effort required in creating new agents from existing ones.
- *Extensibility*: It is the effort required in adding more agents to the multi-agent framework.

Figure 1 below depicts **Quality Prism**. When a ray of quality passes through a Quality Prism, the quality is broken into dimensions. A detailed view of quality has been obtained by putting another Quality Prism that factors the dimensions into quality factors. And placing one more Quality Prism further will split the quality factors into criteria, which can later be mapped, to metrics.

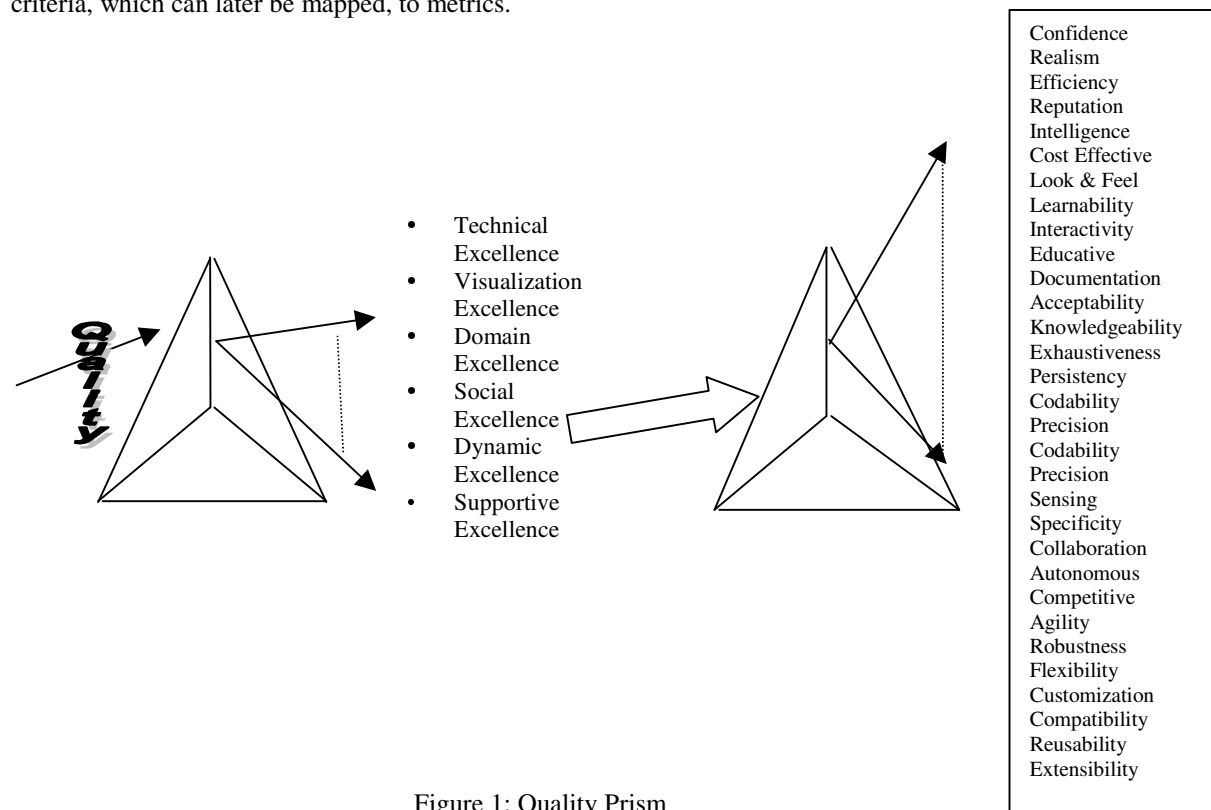


Figure 1: Quality Prism

### 3. Quality Factors and Criteria Relationship in MAS

MAS Quality Model assumes that high-level quality factors of MAS may be defined in terms of criteria. Factors and criteria tend to have a cause-effect relationship. This relationship is shown below:

Table 1: Relationship of dimension, factors and criteria in MAS

Dimension	Quality Factors	Criteria
◆ Technical Excellence	<ul style="list-style-type: none"> <li>• Confidence</li> <li>➤ Realism</li> <li>• Efficiency</li> <li>➤ Reputation</li> <li>• Intelligence</li> <li>➤ Cost Effectiveness</li> </ul>	<ul style="list-style-type: none"> <li>• Consistency</li> <li>• Reliability</li> <li>• Uncertainty handling</li> <li>• Exception handling</li> <li>➤ Verification &amp; Validation</li> <li>➤ Accuracy</li> <li>➤ Self-descriptiveness</li> <li>➤ Completeness</li> <li>• Turnaround time</li> <li>• Response time</li> <li>➤ Consistency</li> <li>➤ Conciseness</li> <li>➤ Benevolence</li> <li>• Reactivity</li> <li>• Interactive</li> <li>• Decisive</li> <li>➤ Goal driven</li> <li>➤ Resource utilization</li> </ul>
◆ Visualization Excellence	<ul style="list-style-type: none"> <li>• Look and Feel</li> <li>➤ Learnability</li> <li>• Educative</li> <li>➤ Documentation</li> <li>• Acceptability</li> </ul>	<ul style="list-style-type: none"> <li>• Clarity</li> <li>• Appearance of system</li> <li>➤ Memorability</li> <li>➤ Understandability</li> <li>➤ Interactive</li> <li>• Completeness</li> <li>• Accuracy</li> <li>• Consistency</li> <li>➤ On line help menus</li> <li>➤ Reference materials</li> <li>➤ User manuals</li> <li>• Simplicity</li> <li>• Goal driven</li> <li>• Communicativeness</li> </ul>
◆ Domain Excellence	<ul style="list-style-type: none"> <li>• Knowledgeability</li> <li>➤ Exhaustiveness</li> <li>• Persistence</li> </ul>	<ul style="list-style-type: none"> <li>• Correctness</li> <li>• Communication richness</li> <li>• Consistency</li> <li>• Coordination</li> <li>• Cooperation</li> <li>• Completeness</li> <li>➤ Communicativeness</li> <li>➤ Conciseness</li> <li>➤ Completeness</li> <li>• Stability</li> <li>• Fault tolerance</li> <li>• Recovery</li> </ul>

- Codability
    - Precision
    - Sensing
    - Specificity
  - Simplicity
    - Self-descriptive
    - Consistency
    - Communicativeness
    - Cooperation
    - Interactive
    - Accuracy
    - Openness
    - Modularity
    - Completeness
    - Consistency
    - Conciseness
    - Interactive
  - ◆ Social Excellence
    - Collaboration
    - Autonomous
    - Competitive
    - Communicative richness
    - Cooperation
    - Coordination
    - Reasoning
    - Decisive
    - Communicative richness
    - Decisive
    - Predictive
    - Proactive
  - ◆ Dynamism Excellence
    - Agility
    - Robustness
    - Flexibility
    - Reactivity
    - Predictive
    - Reasoning
    - Decisive
    - Fault tolerance
    - Simplicity
    - Modularity
    - Decisive
    - Proactive
    - Communicativeness
  - ◆ Supportive Excellence
    - Customization
    - Compatibility
    - Reusability
    - Extensibility
    - Modularity
    - Modifiability
    - Generality
    - Machine independence
    - Generality
    - Modularity
    - Cooperation
    - Coordination
    - Machine independence
    - Generality
    - Modularity
    - Modifiability
    - Machine independence
    - Modularity
    - Generality
- 

#### 4. Evaluation of Quality in MAS

We propose a method to evaluate the quality of MAS. This method is based on factor criteria relationship as defined above. The algorithm is as follows:

1. Prepare the Factor-Criteria matrix  $M$  where  $C_{ij}$  represents the  $J^{\text{th}}$  criteria of  $i^{\text{th}}$  factor. Let  $n$  be the number of factors and  $m$  be the maximum number of criteria for a factor.

Table 2: Factors and Criteria

Factor	Criteria <span style="float: right;">→</span>			
<b>Confidence</b>	Consistency	Reliability	Uncertainty handling	Exception handling
<b>Realism</b>	Verification & Validation	Accuracy	Self-descriptive	Completeness
<b>Efficiency</b>	Turnaround time	Response time		
<b>Reputation</b>	Consistency	Conciseness	Benevolence	
<b>Intelligence</b>	Reactivity	Interactive	Decisive	
<b>Cost Effectiveness</b>	Goal driven	Resource utilization		
<b>Look &amp; Feel</b>	Clarity	Appearance		
<b>Learnability</b>	Memorability	Understandability	Interactive	
<b>Educative</b>	Completeness	Accuracy	Consistency	
<b>Documentation</b>	Help menus	Reference Material	User manual	
<b>Acceptability</b>	Simplicity	Goal driven	Communicative richness	
<b>Knowledgeability</b>	Correctness	Communicativeness	Consistency	Cooperation & Coordination
<b>Exhaustiveness</b>	Communicativeness	Conciseness	Completeness	
<b>Persistence</b>	Stability	Fault tolerance	Recovery	
<b>Codability</b>	Simplicity	Self-descriptive	Consistency	
<b>Precision</b>	Communicativeness	Cooperation		
<b>Sensing</b>	Interactive	Accuracy	Openness	Modularity
<b>Specificity</b>	Completeness	Consistency	Conciseness	Interactive
<b>Collaboration</b>	Communicative richness	Cooperation	Coordination	
<b>Autonomous</b>	Reasoning	Decisive	Communicativeness	
<b>Competitive</b>	Decisive	Predictive	Proactive	
<b>Agility</b>	Reactivity	Predictive	Reasoning	Decisive
<b>Robustness</b>	Fault tolerant	Simplicity	Modularity	
<b>Flexibility</b>	Decisive	Proactive	Communicativeness	
<b>Customization</b>	Modularity	Modifiability	Generality	
<b>Compatibility</b>	Machine independence	Generality	Modularity	Cooperation & Coordination
<b>Reusability</b>	Machine independence	Generality	Modularity	
<b>Extensibility</b>	Modifiability	Machine independence	Generality	Modularity

2. Identify the stakeholders.
3. Obtain the stakeholders choice for quality of MAS in terms of criteria. And  $C_{ij} = 0$  for which stakeholder do not have any interest and 1 otherwise.
4. Compute  $\forall (i=1 \text{ to } n) W_i = \sum C_{ij} (j=1 \text{ to } m)$ .  $W_i$  is a linear array of n factors representing the quality factor in which stakeholders are interested. Highest the value of  $W_i$  for factor, highest is its weightage in terms of stakeholder's interest. Compute a count NF for  $\forall W_i$  where  $W_i < 0$  i.e. the number of factors in which stakeholders are interested.

5. Create another matrix AM that reflects the actual criteria present in the MAS under study where  $AC_{ij}$  represents  $j^{\text{th}}$  criteria of  $i^{\text{th}}$  factor in AM. Now compute  $AW_i$  for MAS under study as  $W_i$  has been defined above.
6. Compare the  $AW_i$  and  $W_i$  to check whether MAS under study is meeting the quality requirements of the stakeholders.
  - a) If  $AW_i \geq W_i$  ( $i=1$  to  $n$ ) then (Quality Check)  $Q_{\text{check}} = +1$  otherwise  $Q_{\text{check}} = -1$ .
7. if  $Q_{\text{check}} = \text{NF}$  then MAS under study is quality SUCCESS else if  $Q_{\text{check}} = 0$  then MAS is satisfying 50 % of quality specified by stakeholders else if  $Q_{\text{CHECK}} < 0$  then MAS needs revision for introduction of quality.

## 5. Conclusions

The agent technology has been applied in a wide range of application domains, including e-commerce, human computer-interfaces, telecommunications and concurrent programming. Large-scale MAS based software development will require support for a diverse range of quality dimensions and respective attributes. In this paper, various facets of quality in MAS have been proposed. And relation between the dimension, quality factors and criteria, which define the overall measures of quality in MAS, has been sought. Then an algorithm to check the quality of MAS quantitatively has been devised. This Quality Model will serve as a useful reference tool to practitioners who manage and build MAS and to researchers who are working on Agent Oriented Software Engineering.

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