Chapter 6
Conclusions and Recommendations for Further Research

6.1 Conclusions

According to the demand on how to implement the intelligent manufacturing to industries, it is very important to introduce a proper direction and philosophy of Intelligent Manufacturing System (IMS). This thesis has already compiled most of the essential principles required to articulate the IMS.

IMS is known as the autonomous or near-autonomous system that can acquire all relevant information through sensing, render decisions for its optimum operation, and implement control functions to achieve the objectives of its manufacturing tasks, including the overhead functions.

The most important sub-systems required for articulating an IMS are machines, intelligence, sensors, actuators, and technologies for integration. There are two essential knowledge bases required for implementing the IMS, knowledge about manufacturing phenomena and knowledge about the available manufacturing processes.

Although the technical detail of how to design an intelligent sensors or the intelligent machines is not presented here, but most of the principles of how to design them are presented.

Axiomatic Design Theory proposed by Suh [38] is one of the distinct theory that based on 2 design axioms, the *Independence Axiom* and the *Information Axiom"*. The axiomatic design defines the design as the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs through the *mapping* between the Functional Requirements (FRs) in the functional domain and the Design Parameters (DPs) of the physical domain. In the case of process design, the DPs in the physical domain are mapped into the process domain in terms of the Process Variables (PVs) which defined as the parameters and quantities controlling the manufacturing process.

Based on the Axiomatic Design Theory, a design can be classified to be a good or bad design by the characteristics of its design matrix. There are 3 kinds of design : Uncouple, Couple, and Decouple Designs. The most preferable design is the Uncouple Design where its design matrix is a diagonal one. For an Uncouple Design, its FRs can be changed independently without affecting any other FRs by varying DPs.

In most research papers, Axiomatic Design Theory is judged to be a good tool for articulating a systematic design process for the intelligent manufacturing system. The intelligent manufacturing system implemented at The University of Tokyo, Japan, is one of the systems that influenced by Axiomatic Design Theory.

Hatamura et al. [10][11] have adopted Suh's [38] concept of Axiomatic Design Theory and extended it to 6 fundamental principles necessary for realizing the intelligent manufacturing system. Figure 4.13 on page 59 is the process of designing an intelligent machine used by his group.

The classification methodology proposed in this thesis is also influenced by Suh's [38] and Hatamura's [10][11] work. The objective of the research began to emerge as a methodology to help the manufacturer to consider the feasibility of introducing the IMS to their production system.

The methodology proposed in this thesis is devised to be a guideline for evaluating the intelligent machines, cells, lines, areas, and the intelligent manufacturing system in order to clarify which subsystem in the overall system to be improved. In addition, the methodology is supposed to be able to broadly answer how higher the level of intelligence can be reached from the lower level.

The core concept of the methodology is developed based on Dhar et al.'s [3] work about the intelligence density which based on the "army type" of intelligence. The proposed methodology is a hierarchy process of evaluation from the lowest tier, machines/equipment, to the topmost in the CIM structure as shown in Figure 5.1 on page 75.

At the lowest tier, machines and equipment will be classified by 15 IDs, as shown in Figure 5.3 on page 77, which finally, leads to the value of imperfection score and the intelligence class.

Cell is the combination of machines and equipment that can be classified by the same technique, but since each cell in the manufacturing system need not to be articulated by the same numbers of machines and equipment. "The system integrity" which is the ability of a system to control and manage its own subsystem then has been adopted and the imperfection score is modified to be the percent of imperfection.

The intelligence scores of each ID are used for indicating the amount and the development direction of a proposed IMS where the imperfection score and the percent of imperfection are used for identifying which parts or subsystems are need to be improved or replaced.

As discussed in Chapter 5, for ease of calculation and translation, it is assumed that both the imperfection score and the intelligent class of each factor in the ID profile have the additive property. However, an important argument about this assumption has emerged that under the actual conditions, those 15 factors in the ID profile may not have the additive property as stated in the assumption.

It may be more reasonable to assume the additive property only among the factors within the same direction in the ID profile and find each summation. This argument is considerably interesting but there is another advantage to find the total summation of the imperfection score.

Since the classification methodology is devised to provide a tool for assessing the level of intelligent of a manufacturing system. It is a guideline for the improvement. Thus the percent of the imperfection score that calculated from the grand total will be helpful for identifying which factor, group, or the direction in the ID profile a manufacturing need to be improved. The exact value of the imperfection score is not important.

With the methodology proposed in this thesis, manufacturers can clearly see the perspective picture of the current status of their manufacturing systems. They then can easily project their organization to a proper direction.

For example, if the intelligence and the imperfection score indicate that most of the weak points of a system fall in the areas of quality of resource or the logistical constraint, it must be recommended to arrange the in-house training program to improve the ability of the human resource and the infrastructure. On the other hand, if most of the imperfection fall in the area of quality of model or the engineering dimensions, the machine and its peripherals must be improved.

However, as generally know, due to the rapid advancement in technology, the criteria used for evaluating the level of intelligence of a specific kind of machine/equipment (such as those 15 IDs) can be arbitrarily increased or dominated by the new one if necessary.

6.2 Discussions

The limitation of the methodology proposed in this thesis can be classified into 2 groups. The first one is about the IMS itself. Since the IMS technology in Thailand is very new. Few or may be none of industries are paying attention to it. It is very difficult to correctly forecast the future development of IMS in Thailand. There is only an expectation that IMS will show its role in the near future because of the rapid changed of technology and business competition.

For industries, at the beginning phase, one of the problems they have to encounter is how to implement the IMS not how to classify it. However, it is not presented here. This thesis supposes that the IMS has already implemented and it need to be classified.

Secondly, the classification methodology proposed in this thesis has to be done by an expert in the organization. Since the methodology is devised to help an organization to identify its current status then the assessor(s) must be the internal staff who are acquainted with the IMS implemented in the system.

One of the practical ways to implement the IMS into an industry is the cooperation between the universities or the laboratories and the industries. The universities and the laboratories will be the sources of IMS concept and technology expertise. After graduation, students from these sources will be scattered to be the experts in the industries and collaboratively work with the universities to create the practical IMS. This is the way The University of Tokyo implement her IMS.

6.3 Recommendations for Further Research

1. Since the methodology proposed in this thesis is used for evaluating the intelligent manufacturing system, but most of the intelligent systems are only implemented in the laboratory. It is difficult to evaluate whether the proposed methodology is reasonable enough or not. For further study, the methodology should be applied to the real system in order to gain the feedback for improving the methodology.
2. The definition of "Machine Intelligence" should be studied and made a better definition in order to make a better group of criteria for the evaluation.
3. The more clearer boundary and the position of each ID in the stretch plot should be studied in order to have enough accurate criteria to position those additional ID to the stretch plot in the future.
4. The measurement unit of the 15 factors in the ID profile should be studied and clarified in order to make a more concrete and reasonable methodology.
5. For more accurate, the dimensions of the 15 factors in the ID profile should be studied in more mathematical detail since the assumption of the additive property may not be definitely correct.
6. The supported software for the evaluation process should be developed in order to reduce the iterative calculation.