The Development of Model for Measuring Railway Wheels Manufacturing Readiness Level

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Abstract. In an effort to grow the railway wheel industry in Indonesia and reduce the dependence on imports, Metal Industries Development Center (MIDC) makes the implementation of the railway wheel manufacturing technology in Indonesia. MIDC is an institution based on research and development having a task to research the production of railway wheels prototype and acts as a supervisor to the industry in Indonesia, for implementing the railway wheel manufacturing technology. The process of implementing manufacturing technology requires a lot of resources. Therefore it is necessary to measure the manufacturing readiness process. Measurement of railway wheels manufacturing readiness was in this study done using the manufacturing readiness level (MRL) model from the United States Department of Defense. MRL consists of 10 manufacturing readiness levels described by 90 criteria and 184 sub-criteria. To get a manufacturing readiness measurement instrument that is good and accurate, the development process involved experts through expert judgment method and validated with a content validity ratio (CVR). Measurement instrument developed in this study consist of 448 indicators. The measurement results show that MIDC’s railway wheels manufacturing readiness is at the level 4. This shows that there is a gap between the current level of manufacturing readiness owned by MIDC and manufacturing readiness levels required to achieve the program objectives, which is level 5. To achieve the program objectives at level 5, a number of actions were required to be done by MIDC. Indicators that must be improved to be able to achieve level 5 are indicators related to the cost and financing, process capability and control, quality management, workers, and manufacturing management criteria.

Keywords: railway wheel manufacturing technology, manufacturing readiness, MRL, CVR

1. Introduction

The Government of Indonesia through the Ministry of Industry has a responsibility to facilitate the improvement of national technological capability that can support the effort to strengthen the national industrial structure (National Industrial Policy, 2008). In line with this, Balai Besar Logam dan Mesin (BBLM) which is an institute under the Ministry of Industry has the responsibility to conduct the
research, development, and engineering process related metal and machinery products. BBLM also serves as a supervisor for the national industry in implementing manufacturing technology resulted from research activities.

One of the studies related to metal raw material products that are currently being carried out by BBLM is a study on the production of railway wheel. The study is done with the aim to apply the manufacturing technology for the production of railway wheel prototype that is expected to encourage the creation of railway wheel industry in the country. To be able to apply the new manufacturing technology, it is necessary to check the manufacturing readiness level of the company. Manufacturing readiness assessment is meant to reduce the risk of failure in the application of manufacturing technologies which can result in loss of money, time, and other resources (Wheeler & Ulsh, 2010).

Manufacturing Readiness Assessment (MRA) is a way to evaluate and determine the level of readiness of a manufacturing company. MRA generates output in the form of readiness status which is stated by Manufacturing Readiness Level (MRL). MRA illustrates the readiness of the manufacturing process, the readiness of the system and product component design, financing and risk management readiness, readiness in humanware and production facilities, as well as the readiness of suppliers to supply quality materials that meet commercial requirements. The output of the MRA is a matrix that describes the level of readiness of a number of factors and their measurement of risk associated with the manufacturing process of the product to be developed (Wheeler & Ulsh, 2010).

Measurement of manufacturing readiness helps to provide an idea of the level of readiness by analysing the manufacturing gap which is a comparison between the level of readiness that is already owned and manufacturing readiness which is needed. The gap can be the basis for the company to understand the improvement efforts that must be done to be able to conduct the railway wheel manufacturing production, in the country. This research aims to design a measurement tool that can be used by BBLM to assess the manufacturing readiness level in the implementation of the railway wheel manufacturing technology.

2. Research Methodology
This research is an exploratory research that aims to gain understanding related to the implementation of a concept/theory. The method used in this study is a qualitative method using Focus Group Discussion (FGD) and interview as tools in data collection process. The design of the measuring instrument was in general carried out in two phases: 1) the development of a measuring instrument based on the theory and 2) the development of measurement tool based on expert judgment, as can be seen in Figure 1. Using the measurement instruments developed in this study, the level of readiness in manufacturing the railway wheels can be measured.

2.1. Measurement instrument design based on theory

The design of the measuring instrument is done by using the basic model of measurement Manufacturing Readiness Level (MRL) (United States Department of Defense, 2012) which has been widely used by various parties in manufacturing readiness level measurement. The advantages of using MRL is the ability to detect the risks that may occur early on the developing a new manufacturing process, as well as the ability to control the execution of the manufacturing process (Stanley, 2008).

MRL consists of 10 manufacturing readiness levels. The manufacturing readiness level is divided based on the life cycle of the technology acquisition process that starts from the research process to the production stage. The stages were ranked starting from the initial phase of research and development.
which is the laboratory level, up to the phase of "full rate production". The definition of stages of the acquisition process into ten manufacturing readiness levels can be seen in Table 1.

**Figure 1.** Stages in designing the instrument for measuring the railway wheels manufacturing readiness level

**Table 1.** The relationship between acquisition stages and MRL (US DoD, 2012)

| Stage of Acquisition | MRL | MRL Definition |
|----------------------|-----|----------------|
| Pre Material Solution Analysis (Basic Research) | Manufacturing Concept Identification | 1. Manufacturing Feasibility Assessed |
|                      | Manufacturing Processes in Laboratory Environment | 2. Manufacturing Concepts Defined |
| Material Solution Analysis | Processes in Relevant Environment | 3. Manufacturing Concepts Developed |
| Technology Development | Processes in Relevant Environment | 4. Capability to produce the technology in a laboratory environment |
| Engineering and Manufacturing Development | Processes and Prototype in Representative Environment | 5. Capability to produce prototype components in a production relevant environment |
|                      | Processes in place Low Rate Production | 6. Capability to produce a prototype system or subsystem in a production relevant environment |
| Production and Deployment | Processes in place Full Rate Production | 7. Capability to produce a prototype system, subsystem or components in a production representative environment |
| Operations and Support | Lean Manufacturing Processes | 8. Pilot line capability demonstrated: ready to begin Low Rate Initial Production |
|                      | Full rate production demonstrated; Capability in place to begin full rate production | 9. Low rate production demonstrated and lean production practice in place |

10. Full rate production demonstrated and lean production practice in place
The design of the measurement instrument began with the development of manufacturing readiness level model. This is done to get a description and definition of each level of readiness in accordance with the stages of acquisition of technology, especially for the railway wheel products. The design of readiness level model is done through analysis at each stage of manufacturing readiness based on literature study.

The development of indicators needs to be done at every level of manufacturing readiness, because every level of readiness has different characteristics. The measurement indicators were developed by defining the criteria and sub-criteria for each level. The criteria and sub-criteria are important factors that must be met by a certain level of readiness. Definition of criteria and sub-criteria at every level were taken from a number of literatures. Based on the US Department of Defense (2012), the criteria and sub-criteria for each level of readiness are described respectively by 9 criteria and 22 sub-criteria (see Table 2). The criteria and sub-criteria were used to assess the status of the manufacturing technology which was subsequently used as a basis in determining the sophistication (maturation) of every level of manufacturing readiness.

2.2. Model development based on FGD and expert interview

The development of model is done through Focus Group Discussion (FGD). Later, using interview method, the development of criteria and sub-criteria were validated by four experts from BBLM who have the competence and experience in the field of manufacturing technology development and its application on railway wheels. The interview process was done by using the questionnaire guidelines that had been previously designed. The questionnaire was designed with the purpose to get approval from experts regarding the criteria and sub-criteria that had been identified based on the theories. A set of questionnaires comprising of 90 criteria and 184 sub-criteria for 10 manufacturing readiness level were assessed using a dichotomy scale “agree” and “disagree”.

Experts were appointed by taking into account several characteristics that include positions in the corporate, educational background, working period at BBLM, and the amount of experience in manufacturing process development activities. The criteria and sub-criteria are calculated using Content Validity Ratio (CVR) method. CVR value indicates the ratio between important or not important scores which was resulted from the assessment by experts (Lawshe, 1975). The criteria and sub-criteria having CVR value > 0 is considered valid.

2.3. Measurement instrument design

The development of measurement instrument begins with the preparation of the items that describe the operational definition of each criteria and sub-criteria. The final measurement instrument consists of 448 indicators. Referring to the Technometer Model, the measurement instrument has a 6 scale in which scale 0 indicates that the activity has not been started or done at all (0%) and scale 5 shows that the activity has been completed perfectly (100%). The measurement of the railway wheels manufacturing readiness was done by assessing the the indicators that have been defined. Assessment results can be calculated by summing the percentage of all the indicators that have been assessed. The result was calculated using the following formula:

$$\sum_{\text{indicator}} \left[0 \times \sum(0) + 0.2 \times \sum(1) + 0.4 \times \sum(2) + 0.6 \times \sum(3) + 0.8 \times \sum(4) + 1.0 \times \sum(5)\right] \times 100\% \over \sum \text{(number of indicators)}$$

The determination of the level of manufacturing readiness can be done based on the total number of indicators for each level. Based on the consensus among the experts, a level of manufacturing readiness can be met if all the amount of the value for the indicators at that level are met with the limit value of 80%.
Table 1. Manufacturing readiness criteria based on MRL US DoD (US DoD, 2012)

| No. | Criteria                          | Operational definition                                                                                                                                                                                                 | Sub-criteria                                             |
|-----|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|
| 1   | Technology and Industrial Base    | The criterion describes the capabilities regarding the technology in the country and its industrial base to support the design of products, development, production, operation, maintenance support, and also the impacts on the environment. | Industrial base, Manufacturing technology development     |
| 2   | Design                            | The criterion provides an overview of maturity and stability of the system design, product design, and the associated impact on manufacturing readiness. This criterion also includes produceability and design maturity. | Produceability program, Design maturity                  |
| 3   | Cost and Funding                  | Cost and Funding The criterion describes the ability of financing. It includes the risks regarding the cost and production financing. It is necessary to perform cost analysis, production cost estimation, as well as investment cost analysis. | Production cost knowledge (cost modeling), Cost analysis, Manufacturing investment budget |
| 4   | Materials                         | The criterion describes the material needs and its risks (including raw materials, components, subassemblies, and parts of semi-finished). This criterion also describes the level of material readiness, availability, supply chain management, and special handling of existing material such as the government's permission, safety, and the storage environment. | Maturity, Availability, Supply chain management, Special handling |
| 5   | Process Capability and Control    | This criterion describes how the manufacturing process can reflect the design of the product (repeatability and affordability). This criterion also includes modeling and simulation (products and processes), the maturity of the manufacturing process and productivity. | Modeling and simulation of production and process, Manufacturing process maturity, Process yields and rates |
| 6   | Quality Management                | This criterion illustrates the risk and effort of management to control the quality and to encourage continuous improvement. Management quality also includes quality of suppliers. | Quality Management including Supplier Quality, Product Quality, Supplier Quality Management |
| 7   | Manufacturing Workforce (Engineering and Production) | The criterion includes the ability of labor both technical and production, including the required skills, availability and the amount required to support the manufacturing process. This criterion also includes production planning and scheduling, materials planning, and equipment inspection. | Manufacturing workforce |
| 8   | Facilities                        | This criterion describes the capabilities and capacity related to major manufacturing facilities, subcontractors, suppliers, vendors, and maintenance/repair equipment. | Tooling special test equipment, special inspection equipment, Facilities |
| 9   | Manufacturing Management          | The criterion provides an overview of maturity and stability of the system design, product design, and the associated impact on manufacturing readiness. This criterion also includes produceability and design maturity. | Manufacturing planning and scheduling, Materials planning |
3. Result and analysis

The development of manufacturing readiness assessment model for railway wheels on BBLM was done through FGD and interview method. The assessment results show that for level 5 readiness, the measurement value (score) is 71.94%, which means that the value limit is not met. Based on this result it is known that the level of manufacturing readiness is still at level 4 which indicates the ability to implement the production technology in a laboratory environment.

The measurement results show that BBLM still need to make improvements for some indicators are not sufficient to meet the level 5 requirements, i.e. indicators for the criteria of cost and financing, ability to process and control, quality management, manufacturing workforce and manufacturing management. The explanation related to the improvement efforts for those criteria is as follows:

- For the criteria of cost and financing, ability for cost control in prototypes development in a production environment should be developed. Besides, the risk analysis related to the cost management should be prepared.
- Related process control capabilities, improvements in the process of developing a prototype simulation is needed to increase the prototype production capability in a production environment.
- To support and maintain the quality of the production process in accordance with the target, efforts are needed to implement quality management concept. Product quality strategy is a key to the success of sustainable production processes. In addition to the implementation of the company's internal quality management, quality management practices also also should be applied to who will supply the raw material for the production of railway wheel prototype.
- Transition from laboratory research into the field of production requires higher skilled workers. Skill improvement can be done by taking into account the results of the indicators measurement.
- To be able to carry out the production process, the support of the company's management is required. Improvements in the planning and scheduling of manufacturing processes as well as the material needs to support the production of railway wheels prototype are very important to be implemented.

4. Conclusion

A measurement tool for railway wheels manufacturing readiness at BBLM had been designed. The measurement instrument consists of 10 levels of readiness and was described by 90 criteria, 184 sub-criteria and 448 indicators, scattered in each level as a reference for measuring the manufacturing readiness. Based on the data processing results it was shown that the railway wheel manufacturing readiness of BBLM is at level 4. These results indicate that the readiness is still at the stage of manufacturing the technology in a laboratory environment. To be able to undertake the production of railway wheel in a real production environment, BBLM still needs to make improvements related to some indicators including indicators for the criteria of cost and financing, ability to process and control, quality management, manufacturing workforce and manufacturing management.

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