

# Measuring Machine Reconfigurability by a Novel Method in Reconfigurable Manufacturing System Configuration

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## Abstract

Reconfigurable Manufacturing Systems (RMS) are designed to rapidly adjust production capacity and functionality in response to changing market demands, product variety, and technological advancements. A critical characteristic of RMS is machine reconfigurability, which determines how effectively a machine or manufacturing system can adapt to new production requirements with minimum time, effort, and cost. This research paper proposes a novel quantitative method for measuring machine reconfigurability in RMS configuration. The proposed method integrates modularity, scalability, convertibility, customization, integrability, and diagnosability into a unified Reconfigurability Index (RI). Mathematical models, weighted evaluation criteria, and performance equations are developed to assess machine adaptability. A comparative analysis between traditional methods and the proposed approach demonstrates improved accuracy and practical applicability. Graphical illustrations and numerical examples validate the effectiveness of the proposed methodology.

**Keywords:** Reconfigurable Manufacturing System, Machine Reconfigurability, Reconfigurability Index, RMS Configuration, Manufacturing Flexibility.

## 1. Introduction

Modern manufacturing industries are operating in an environment characterized by rapid technological advancements, intense global competition, fluctuating market demands, and increasing customer expectations for customized products. Customers today demand high-quality products with shorter delivery times and lower costs. At the same time, product life cycles are becoming increasingly shorter due to continuous innovation and changing consumer preferences. These challenges require manufacturing systems that are not only efficient and productive but also highly adaptable and responsive to change. Traditional manufacturing systems, particularly Dedicated Manufacturing Systems (DMS), were primarily designed for mass production of a single product or a limited range of products. Although DMS provides high productivity and low production cost for stable market conditions, it lacks the flexibility required to accommodate frequent design modifications, product variations, and changing production volumes. Any significant change in product design or market demand often requires

extensive machine replacement, system redesign, and high reconfiguration cost. To address some of these limitations, Flexible Manufacturing Systems (FMS) were developed. FMS allows the production of different product types through programmable machines and automated control systems. These systems provide greater flexibility compared to DMS; however, they often suffer from excessive flexibility, complex system architecture, high investment cost, and complicated maintenance requirements. In many industrial applications, the flexibility offered by FMS exceeds actual production needs, resulting in inefficient utilization of resources and increased operational expenses. To overcome the limitations of both DMS and FMS, the concept of Reconfigurable Manufacturing Systems (RMS) was introduced as an advanced manufacturing paradigm capable of providing customized flexibility and scalability according to production requirements. RMS is specifically designed to rapidly adjust production functionality and capacity in response to market changes while maintaining high productivity and cost efficiency. An RMS is designed with adjustable system structures, scalable production capacity, modular machine tools, and flexible control mechanisms that can be rapidly reconfigured according to changing production requirements. Unlike traditional manufacturing systems, RMS focuses on providing exactly the required functionality and capacity when needed. This enables manufacturers to respond quickly to changes in product design, demand fluctuations, and technological developments. The efficiency and performance of an RMS largely depend on machine reconfigurability. Machine reconfigurability refers to the capability of a manufacturing machine to modify its structure, functionality, production capacity, and operational sequence with minimum time, effort, and cost. A highly reconfigurable machine can efficiently adapt to new product families, integrate additional modules, and accommodate future manufacturing requirements without complete system replacement. Machine reconfigurability generally includes the following capabilities: Change production functionality Adapt production capacity, Integrate new modules Modify operational sequences Reduce reconfiguration time and cost. In addition to these capabilities, machine reconfigurability also supports improved system responsiveness, reduced downtime, enhanced productivity, and better resource utilization. Therefore, it has become one of the most important characteristics in modern manufacturing environments, particularly in Industry 4.0 and smart factory applications. Several researchers have proposed different methods for evaluating reconfigurability, including qualitative assessment methods, flexibility indices, cost-based approaches, fuzzy logic models, and multi-criteria decision-making techniques. Although these approaches contribute significantly to RMS evaluation, many existing methods suffer from limitations such as subjective judgment, computational complexity, lack of industrial applicability, and inability to provide a unified quantitative measure of reconfigurability. Most existing approaches evaluate only individual characteristics of reconfigurability separately rather than integrating all important factors into a single comprehensive framework. Consequently, industries often face difficulties in objectively comparing different manufacturing machines and selecting the most suitable RMS configuration. Therefore, there is a strong need for a comprehensive, accurate, and practical method for measuring machine reconfigurability. In response to this requirement, this paper introduces a novel method for measuring machine reconfigurability using a comprehensive Reconfigurability Index (RI). The proposed method integrates key reconfigurability characteristics such as modularity, scalability, convertibility, integrability, diagnosability, and customization into a unified mathematical framework. The proposed Reconfigurability Index provides a quantitative measure for evaluating machine adaptability and supports effective decision-making in RMS configuration. The methodology aims to improve industrial applicability, simplify evaluation procedures, and provide a

reliable basis for designing efficient and adaptive manufacturing systems suitable for dynamic production environments.

## Literature Review

Several researchers have contributed to RMS and reconfigurability measurement.

### Reconfigurable Manufacturing Systems

Koren et al. introduced RMS as a manufacturing paradigm capable of providing customized flexibility and scalability.

Mehrabi et al. discussed RMS characteristics including:

1. Modularity
2. Integrability
3. Scalability
4. Convertibility
5. Diagnosability
6. Customization

### Existing Reconfigurability Measurement Methods

Traditional methods include:

Method	Limitation
Qualitative Assessment	Subjective evaluation
Cost-Based Method	Ignores technical adaptability
Flexibility Index	Does not measure structural change
Multi-Criteria Decision Models	Complex calculations
Fuzzy Logic Models	Difficult industrial implementation

Most existing approaches focus on isolated parameters rather than a combined evaluation.

### Objectives of the Study

The major objectives of this research are:

1. To develop a novel quantitative method for measuring machine reconfigurability.
2. To establish a comprehensive Reconfigurability Index (RI).
3. To integrate multiple RMS characteristics into a single mathematical framework.
4. To validate the proposed method through numerical analysis.
5. To compare the proposed method with conventional approaches.

### **Characteristics of Machine Reconfigurability**

The proposed method evaluates six important characteristics.

#### **Modularity (M)**

Modularity represents the ease of adding or removing machine modules.

$$[ M = ]$$

Where:

- (N<sub>r</sub>) = Number of replaceable modules
- (N<sub>t</sub>) = Total number of modules

#### **Scalability (S)**

Scalability measures the ability to increase or decrease production capacity.

$$[ S = ]$$

Where:

- (C<sub>m</sub>) = Current machine capacity
- (C<sub>{max}</sub>) = Maximum achievable capacity

#### **Convertibility (C)**

Convertibility refers to the ability to switch between different product types.

$$[ C = ]$$

Where:

- (P<sub>a</sub>) = Number of adaptable products
- (P<sub>t</sub>) = Total product variants

#### **Integrability (I)**

Integrability measures compatibility with other systems.

$$[ I = ]$$

Where:

- (N<sub>c</sub>) = Number of compatible systems
- (N<sub>s</sub>) = Total systems considered

#### **Diagnosability (D)**

Diagnosability evaluates fault detection capability.

$$[ D = ]$$

Where:

- $(F_d)$  = Detected faults
- $(F_t)$  = Total faults

Customization (CU)

Customization indicates the ability to satisfy custom production requirements.

$$[ CU = ]$$

Where:

- $(O_c)$  = Customized operations
- $(O_t)$  = Total operations

### Proposed Novel Reconfigurability Measurement Method

The proposed method combines all six characteristics using weighted parameters.

Reconfigurability Index (RI)

$$[ RI = w_1M + w_2S + w_3C + w_4I + w_5D + w_6CU ]$$

Subject to:

$$[ w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1 ]$$

Where:

- $(w_i)$  = Weight assigned to each characteristic

Weight Assignment

The weights are determined using industrial importance.

Parameter	Weight
Modularity	0.20
Scalability	0.15
Convertibility	0.20
Integrability	0.15
Diagnosability	0.10
Customization	0.20

### Mathematical Modeling

Suppose an RMS machine has the following values:

Parameter	Value
M	0.85
S	0.70
C	0.90
I	0.75
D	0.80
CU	0.88

Using the proposed equation:

$$[ RI = (0.20)(0.85) + (0.15)(0.70) + (0.20)(0.90) + (0.15)(0.75) + (0.10)(0.80) + (0.20)(0.88) ]$$

$$[ RI = 0.17 + 0.105 + 0.18 + 0.1125 + 0.08 + 0.176 ]$$

$$[ RI = 0.8235 ]$$

Thus, the machine possesses high reconfigurability.

### Reconfigurability Classification

RI Range	Reconfigurability Level
0.00 – 0.30	Low
0.31 – 0.60	Moderate
0.61 – 0.80	High
0.81 – 1.00	Very High

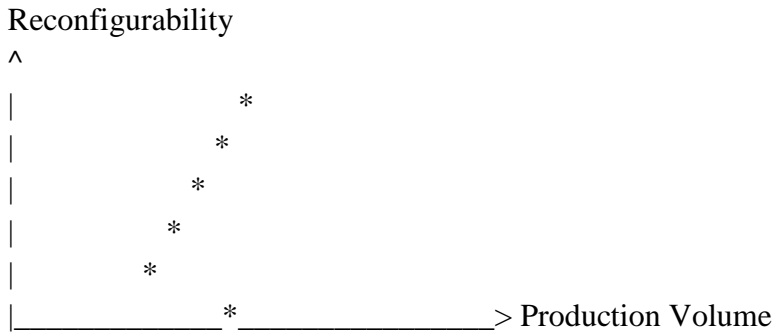
The obtained RI value of 0.8235 indicates very high reconfigurability.

### Graphical Analysis of Reconfigurable Manufacturing Systems

Graphical analysis is an important part of research on Reconfigurable Manufacturing Systems (RMS). It helps in understanding system performance, machine reconfigurability, scalability, flexibility, productivity, and cost efficiency through visual representation of data.

### Reconfigurability vs Production Volume Graph

This graph shows how machine reconfigurability changes with production demand.



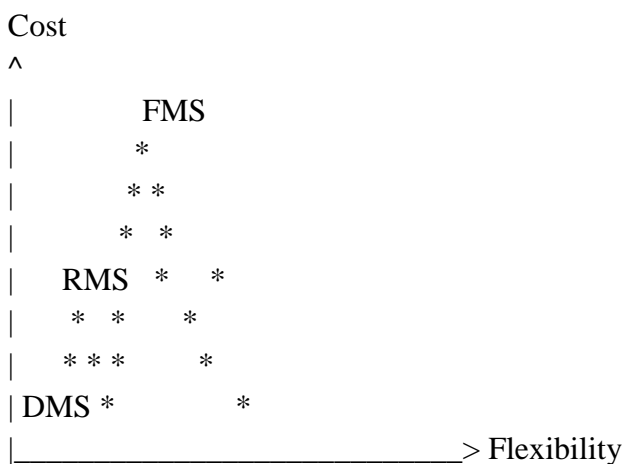
### Interpretation

- As production volume increases, reconfigurability requirements also increase.
- RMS adapts efficiently to changing market demands.
- High production variation requires greater machine scalability and modularity.

### Production Cost Comparison

Comparison among:

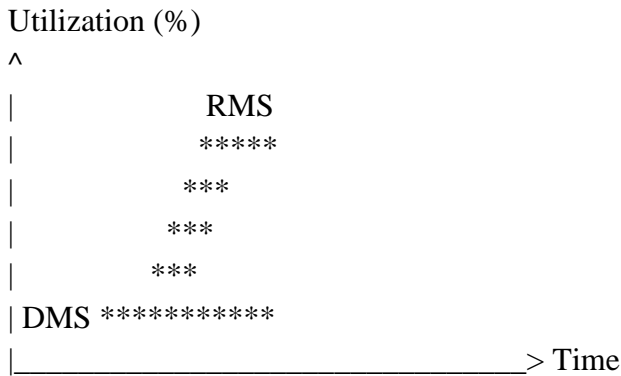
- Dedicated Manufacturing System (DMS)
- Flexible Manufacturing System (FMS)
- Reconfigurable Manufacturing System (RMS)



### Interpretation

- DMS has low flexibility and low cost.
- FMS provides maximum flexibility but very high cost.
- RMS provides balanced flexibility with moderate cost.

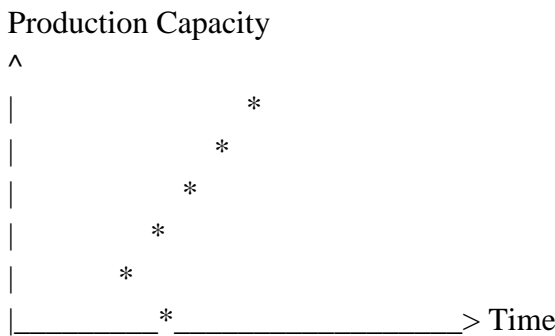
### Machine Utilization Graph



### Interpretation

- RMS maintains higher machine utilization over time.
- Reconfiguration reduces idle time.
- Better adaptability improves operational efficiency.

### Scalability Analysis



### Interpretation

- RMS allows gradual increase in production capacity.
- Scalability supports market expansion.
- Additional modules can be integrated without complete redesign.

### Conclusion

Graphical analysis of RMS demonstrates that:

- Reconfigurable systems provide high efficiency and adaptability.
- RMS achieves a balance between cost and flexibility.
- Production scalability and reduced downtime improve industrial productivity.
- RMS is highly suitable for Industry 4.0 and smart manufacturing environments.

## **Applications of Reconfigurable Manufacturing Systems**

Reconfigurable Manufacturing Systems (RMS) are widely used in modern industries where product demand, product design, and production volume change frequently. RMS provides scalability, convertibility, modularity, customization, and flexibility, making it suitable for dynamic manufacturing environments.

### **Automobile Industry**

The automobile industry is one of the major application areas of RMS because vehicle models and customer demands change rapidly.

#### **Applications**

- Manufacturing of engines, gearboxes, chassis, and body parts
- Production line adjustment for different car models
- Rapid switching between petrol, diesel, electric, and hybrid vehicle components
- Capacity expansion during high market demand

#### **Advantages**

- Reduces downtime during model changeovers
- Enables quick introduction of new vehicle variants
- Improves production efficiency
- Supports mass customization.

#### **Example**

A car manufacturer can reconfigure robotic welding stations and CNC machines to produce SUV components instead of sedan components without replacing the entire production system.

### **Aerospace Industry**

Aerospace manufacturing requires high precision and frequent design modifications.

#### **Applications**

- Aircraft structural component manufacturing
- Turbine blade production
- Satellite and spacecraft component fabrication
- Precision drilling and machining operations

#### **Advantages**

- Handles complex geometries efficiently

- Supports low-volume, high-variety production
- Allows rapid adaptation to new aircraft designs
- Improves machine utilization

## Example

Reconfigurable robotic systems can be adjusted to manufacture different aircraft wing structures according to design specifications.

## Electronics Manufacturing

Electronic products have short life cycles and rapid technological changes.

## Applications

- Printed Circuit Board (PCB) assembly
- Smartphone and laptop manufacturing
- Semiconductor component production
- Automated testing systems

## Advantages

- Quick adaptation to new electronic models
- Reduces production cost
- Enhances product quality
- Supports high-speed automated production

## Example

An RMS can rapidly switch production from one smartphone model to another by reprogramming robots and changing modular fixtures.

## Medical Equipment Manufacturing

Medical industries require customized and highly precise manufacturing systems.

## Applications

- Surgical instrument manufacturing
- Medical implant production
- Diagnostic equipment assembly
- Pharmaceutical packaging systems

**Advantages**

- Enables customized medical products
- Maintains high precision and reliability
- Supports rapid production during emergencies
- Reduces setup time

**Example**

During pandemics, RMS can be reconfigured quickly for ventilator or medical device production.

**Defense Industry**

Defense production often requires highly specialized and rapidly changing manufacturing systems.

**Applications**

- Weapon system components
- Military vehicle manufacturing
- Radar and communication systems
- Ammunition component production

**Advantages**

- Rapid response to defense requirements
- High production accuracy
- Better security and automation
- Adaptability to changing defense technologies

**Example**

A defense factory may reconfigure machining centers to manufacture different missile components based on mission requirements.

**Renewable Energy Sector**

Renewable energy systems require various specialized components.

**Applications**

- Wind turbine blade manufacturing
- Solar panel assembly
- Battery pack production
- Electric vehicle battery systems

## Advantages

- Supports emerging green technologies
- Facilitates scalable production
- Adapts to evolving energy technologies
- Improves sustainability

## Example

RMS can modify assembly systems to produce different sizes of solar panels depending on market demand.

## Consumer Goods Manufacturing

Consumer markets require frequent product updates and customization.

## Applications

- Home appliance manufacturing
- Furniture production
- Plastic goods manufacturing
- Packaging industries

## Advantages

- Handles seasonal demand variation
- Supports product variety
- Reduces inventory costs
- Improves responsiveness to customer trends

## Example

A furniture company can reconfigure automated cutting and assembly systems to manufacture different furniture designs.

## CNC and Machine Tool Industries

RMS is highly applicable in modern machine tool systems.

## Applications

- Modular CNC machining centers
- Multi-axis machining systems
- Flexible robotic cells
- Automated material handling systems

**Advantages**

- Enhances machine utilization
- Simplifies maintenance
- Enables scalable production
- Reduces operational cost

**Example**

A modular CNC system can add or remove spindle units according to production requirements.

**Smart Factories and Industry 4.0**

RMS plays an important role in intelligent manufacturing environments.

**Applications**

- IoT-enabled manufacturing systems
- Cyber-physical production systems
- AI-based adaptive production
- Digital twin manufacturing

**Advantages**

- Real-time production monitoring
- Automated decision making
- Improved productivity
- Predictive maintenance capability

**Example**

Smart factories use RMS integrated with sensors and AI to automatically adjust production lines according to demand fluctuations.

**Mass Customization Production**

Modern customers demand personalized products.

**Applications**

- Customized automobiles
- Personalized electronic gadgets
- Tailored consumer products
- Customized industrial equipment

**Advantages**

- Produces customized products economically
- Reduces production delays
- Increases customer satisfaction
- Enhances market competitiveness

**Example**

A manufacturing line can be reconfigured automatically to produce products with different specifications for different customers.

**Educational and Research Laboratories**

Universities and research institutes use RMS for advanced manufacturing studies.

**Applications**

- Manufacturing system simulation
- Robotics and automation research
- Machine reconfigurability analysis
- Smart manufacturing experiments

**Advantages**

- Supports innovation and experimentation
- Reduces research cost
- Enhances technical education
- Provides real industrial exposure.

**Small and Medium Enterprises (SMEs)**

RMS is beneficial for SMEs due to limited resources and changing customer demands.

**Applications**

- Batch production systems
- Job shop manufacturing
- Customized component production
- Multi-product manufacturing

**Advantages**

- Low investment compared to full FMS
- Better resource utilization

- Improved production flexibility
- Increased competitiveness

## Conclusion

Reconfigurable Manufacturing Systems are essential for modern industries because they provide:

- High flexibility
- Scalability
- Rapid adaptability
- Reduced production cost
- Improved productivity
- Better customization capability

RMS bridges the gap between Dedicated Manufacturing Systems and Flexible Manufacturing Systems, making it a key technology for future smart manufacturing and Industry 4.0 environments.

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