Applying analytical hierarchy process for addressing the agile manufacturing drivers

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Abstract. In order to incorporate agile manufacturing (AM) in materials and systems, the manufacturing sectors have drivers to face obstacles. Agility is generally accepted for satisfying diverse consumer demands as a new strategic principle in the automotive industry. There has now been a prerequisite for evaluating AM in industry. An organization's effectiveness relies on their ability to find and pay special attention to the crucial success drivers to achieve a high level of efficiency. This paper suggests a number of Agile Manufacturing Drivers (AMDs) to evaluate AM that is deemed suitable to the production industry. In order to prioritise performance drivers, the analytical hierarchy process (AHP) approach is used to summarise the perspective of an expert. The proposed AMDs are believed to encourage and assist the manufacturing sector in producing agile products to achieve higher efficiency so as to improve competition.

Keywords: Agile manufacturing (AM), Agile manufacturing drivers (AMDs), Analytical hierarchy process (AHP), Consistency Ratio (C.R.), Consistency Index (C.I.), Random Index (R.I.).

1. Introduction
The definition of agile manufacturing (AM) was first published by the Iacocca Institute at Lehigh University in the 21st century Enterprise Strategy report [1].

AM has already been taken into account by analysts, administrators or consultants. Today businesses continue to restructure and refurbish to meet challenging consumers' challenges, who shift their needs quickly [2]. Customer trends and technical needs push suppliers to implement innovative business models to be competitive on the market. Since "shift" seems to be one of the key features, companies intend to follow (AM), since it rapidly embraces evolving environments. Agility allows companies to compete in an unpredictable and constantly changing business climate [3]. Given the outcome of economy of scale and mass production in uncomplicated plants, it is important to create more versatile and sensitive organisations [2][4]. Companies now consider speed, pricing and versatility, rather than costs that are stressed to meet the specific demands of consumers and industries, to address market uncertainty [5].

The Agility System offers an industry forum that enables them to take advantage of current and evolving business opportunities [6] [7]. The four principal elements of AM must be well understood before its introduction, including AMDs, strategic capacities, agility providers and agility ability [8]. In order to adapt to the reforms, some AMDs are expected to compel an organisation to reconsider its current approach, to implement an agility strategy and to acknowledge the need for agility. The agility
suppliers do not always rely and need to be centred on multiple classifications by the policymakers. Strong venture capital, high technology and high integrated products sectors are the automotive industries. In this unpredictable and evolving market, the AM framework serves as a strategic initiative to respond to dynamic demand of customer with efficient costs, for the benefit of a machine agility, used the informative diagram of control and a table model and a decision tree model. So we may conclude that agile production allows the company to succeed in this age of constant and competitive consumer shifts. [9].

The research did not however lead to a study of the interrelationship between AMDs, [10] noted that few components contribute successfully to improving agility from a range of facilitators. A number of facilitators must also be investigated and their relationship investigated. Furthermore, it is important to prioritise AMDs. Example the performance of car firms relies largely on the manufacturer and dealer relationship, which is why the complexity of the partnership is examined by a methodology with a broad number of device variables, which serve as driving forces [11]. It was widely believed that there are challenges in managing complicated situations or structures for people or organisations of policymakers. The ambiguity of the problems or structures is caused by a wide range of elements and relationships between them. ISM provides a greater view of the structure of a function and provides valuable guidance to generate a structure graphical representation [12]. The processing of the AMDs organised by ISM takes the form of a successful AHP operation, which is their individual contribution to the realisation of agile development. The study helps managers to develop policies which maintain their individual value in the effective implementation of AM in view of complex interdependence among drivers. This will help decide whether to take preventive action to tackle these drivers.

2. Literature Review
Following the development of the concepts of agile production, the researchers started conducting studies to determine AMDs to help businesses apply AM principles. These research has been published in literature on a variety of occasions. In these research papers the agility defined by the authors is listed in Table 1.

| S.No | AMDs                                | [13] | [14] | [15] | [16] |
|------|------------------------------------|------|------|------|------|
| 1    | Responsive Supply Chain            | ✓    |      |      |      |
| 2    | Top management support             | ✓    | ✓    |      |      |
| 3    | Training and Education             | ✓    |      |      |      |
| 4    | Customer response adoption         |      |      | ✓    |      |
| 5    | Concurrent engineering             | ✓    | ✓    |      |      |
| 6    | Re-configurable layout             | ✓    |      |      |      |
| 7    | Appropriate Hardware               |      | ✓    |      |      |
| 8    | Rapid prototyping                  |      |      | ✓    |      |
| 9    | Organisational Culture             |      | ✓    |      |      |
| 10   | Customer Involvement               |      |      | ✓    |      |
| 11   | Knowledgeable Workers              |      |      | ✓    |      |
| 12   | Employee involvement               |      |      | ✓    |      |
| 13   | Proper database management         |      | ✓    |      |      |
| 14   | Automation                         | ✓    |      |      |      |
| 15   | Virtual Enterprise                 | ✓    | ✓    |      |      |
| 16   | IT Integrations                    | ✓    | ✓    |      |      |

An summary of the Table 1 material indicates that rapid prototyping and virtual enterprise are also referred to as agile production facilitators. Rapid prototyping helps fast prototyping development so that firms can reconfigure the goods to meet their customer's needs prior to actually producing the product on the shop floor. In addition, the virtual enterprise allows the company to unite other companies temporarily to take benefit from changing markets. The virtual enterprise willingness to
make use of other companies’ capability to incorporate them into its product factory to satisfy the complex demands of customers’ manufacturing process. At this point, researchers assessed the potential of the IT integration model to improve the virtual enterprise and configurable abilities of companies to gain agility assets in the last few years.

The IT integration model has the ability to help organisations, through the use of IT tools, acquire the information they need for agile enterprises within the minimum period. In addition to rapid prototyping and virtual company management, AMD is often required for the storing and use of previous works in the proper database management. Critical thinking would suggest that the output monitoring for product creation is complicated without the help of proper database management. As previously mentioned, they all support other AMDs and have their relationship with one another in the ISM model and are assessed by AHP for their efficacy in agile production.

3. AHP Methodology

AHP is an "analytical hierarchy process" originating in 1977 by Satty. For the outcome of ISM, AHP is used. The ISM model is designed to establish the hierarchy of AMDs defined (Figure 1). Since that model, the ISM results in a hypothetical hierarchy that requires quantitative analysis for the efficacy of its percentage. ISM is used to build relationships between AMDs, as it is an uninterrupted, logical methodology [17]. Thus, the ISM model’s soundness can be checked using AHP. In the 70s AHP had its origins and was tremendously employed by Thomas L. Saaty, who was present for the decisions for intricate situations when human consciousness, views and effects were taken together [18]. Their results were long-term. In order to examine and differentiate the AHP application in an independent way, it begins with a problem which is divided into a hierarchy of criteria. By comparing the available options, alternatives or variables for each selected benchmark or criteria in the same way, decision makers can properly review them. In order to enter subjacent information, the comparison can use existing data from the criteria and human judgments [19].

At the strategic level of planning AHP has been widely used to take complex decisions [20]. AHP converts the most frequently real comparisons, into an analysed and comparable numeric number. The weight of each AMDs ensures that each element within the defined hierarchy is properly evaluated [21]. The primary uniqueness of the AHP methodology when compared with other methodologies is this opportunity to change empirical evidence into mathematical modelling.

After all comparisons are made, relative weights are developed between each criterion and the probability calculations for each alternative are calculated. This probability assesses potential for alternative to implement expected targets. More likely alternative is, more likely final goal will be reached. Comparison is made in parallel to determine each alternative's comparative importance. The judge must show his opinion in this method that he re-holds the importance of a single comparison on pairs (Fig 2). A variable parallel comparison will allow the variable to calculate priority and meaning weights. When we compare two components, we obey the straight forward rule suggested by Saaty [21].

As priorities are only recognised if a consistency check is obtained from consistent matrices. The Consistency Index (CI) has been found by Saaty [21], obtained through the own value method:
Figure 1 ISM model

Figure 2 AHP Model
Judge-1

We categorize ten AMDs ranks by ten groups from D1 to D10 in this pair-scale comparison.

Table 2 Groups of AMDs

| Groups | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|--------|----|----|----|----|----|----|----|----|----|------|
| AMDs   | 2  | 3  | 11.12 | 9 | 13.16 | 4.10 | 6.7 | 5.14 | 15 | 8 | 1 |
| Intensity of Importance | 1 | 1.89 | 2.78 | 3.67 | 4.55 | 5.44 | 6.33 | 7.22 | 8.11 | 9 |
| Reciprocal | 1 | 0.53 | 0.36 | 0.27 | 0.22 | 0.18 | 0.16 | 0.14 | 0.12 | 0.11 |

Table 3 Pairwise comparison matrix

| AMDs | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|
| 1 | 0.11 | 0.36 | 0.53 | 0.27 | 0.36 | 0.36 | 0.14 | 0.14 | 0.18 | 0.36 | 0.36 | 0.36 | 0.18 | 0.18 | 0.18 |
| 2 | 1 | 1.86 | 5.45 | 7.22 | 6.33 | 6.33 | 8.11 | 3.67 | 5.45 | 2.78 | 2.78 | 4.56 | 7.22 | 7.22 | 4.56 |
| 3 | 8.11 | 0.53 | 1 | 4.56 | 6.33 | 5.45 | 5.45 | 7.22 | 2.78 | 4.56 | 1.89 | 1.89 | 3.67 | 6.33 | 6.33 | 3.67 |
| 4 | 4.56 | 0.18 | 0.22 | 1 | 2.78 | 1.89 | 1.89 | 3.67 | 0.36 | 1 | 0.27 | 0.27 | 0.53 | 2.78 | 2.78 | 0.53 |
| 5 | 2.78 | 0.14 | 0.16 | 0.36 | 1 | 0.53 | 0.53 | 1.89 | 0.22 | 0.36 | 0.18 | 0.18 | 0.18 | 0.27 | 1 | 0.27 |
| 6 | 3.67 | 0.16 | 0.18 | 0.53 | 1.89 | 1 | 1 | 2.78 | 0.27 | 0.53 | 0.22 | 0.22 | 0.36 | 0.18 | 1.89 | 1.89 | 0.36 |
| 7 | 3.67 | 0.16 | 0.18 | 0.53 | 1.89 | 1 | 1 | 2.78 | 0.27 | 0.53 | 0.22 | 0.22 | 0.36 | 0.18 | 1.89 | 1.89 | 0.36 |
| 8 | 1.89 | 0.12 | 0.14 | 0.27 | 0.53 | 0.36 | 0.36 | 1 | 0.18 | 0.27 | 0.16 | 0.16 | 0.22 | 0.53 | 0.53 | 0.22 |
| 9 | 6.33 | 0.27 | 0.36 | 2.78 | 4.56 | 3.67 | 3.67 | 5.45 | 1 | 2.78 | 0.53 | 0.53 | 1.89 | 4.56 | 4.56 | 1.89 |
| 10 | 4.56 | 0.18 | 0.22 | 1 | 2.78 | 1.89 | 1.89 | 3.67 | 0.36 | 1 | 0.27 | 0.27 | 0.53 | 2.78 | 2.78 | 0.53 |
| 11 | 7.22 | 0.36 | 0.53 | 3.67 | 5.45 | 4.56 | 4.56 | 6.33 | 1.89 | 3.67 | 1 | 1 | 2.78 | 5.45 | 5.45 | 2.78 |
| 12 | 7.22 | 0.36 | 0.53 | 3.67 | 5.45 | 4.56 | 4.56 | 6.33 | 1.89 | 3.67 | 1 | 1 | 2.78 | 5.45 | 5.45 | 2.78 |
| 13 | 5.45 | 0.22 | 0.27 | 1.89 | 3.67 | 2.78 | 2.78 | 4.56 | 0.53 | 1.89 | 0.36 | 0.36 | 1 | 3.67 | 3.67 | 1 |
| 14 | 2.78 | 0.14 | 0.16 | 0.36 | 1 | 0.53 | 0.53 | 1.89 | 0.22 | 0.36 | 0.18 | 0.18 | 0.27 | 1 | 1 | 0.27 |
| 15 | 2.78 | 0.14 | 0.16 | 0.36 | 1 | 0.53 | 0.53 | 1.89 | 0.22 | 0.36 | 0.18 | 0.18 | 0.27 | 1 | 1 | 0.27 |
| 16 | 5.45 | 0.22 | 0.27 | 1.89 | 3.67 | 2.78 | 2.78 | 4.56 | 0.53 | 1.89 | 0.36 | 0.36 | 1 | 3.67 | 3.67 | 1 |

Table 4 Calculation of priority weight (W) and eigenvector \( \lambda_{max} \)

| AMDs | SQUR(P) | \( \omega \) | \( \lambda_{max} \) | \( \lambda_{max} \) = 17.20644481 |
|------|---------|---------|------------------|------------------|
| 1    | 0.24032608 | 0.0103947 | 0.17885652 | 17.20644484 |
| 2    | 4.57057614 | 0.19768914 | 3.38304393 | 17.1129476 |
| 3    | 3.55331495 | 0.15369028 | 2.56784005 | 16.766446 |
| 4    | 0.9423191 | 0.04035780 | 0.66954633 | 16.4274396 |
| 5    | 0.44416837 | 0.01922146 | 0.31532210 | 16.4132226 |
| 6    | 0.64731231 | 0.02799797 | 0.45881281 | 16.387358 |
| 7    | 0.64731231 | 0.02799797 | 0.45881281 | 16.387358 |
| 8    | 0.3165713 | 0.0136925 | 0.22906919 | 16.7294766 |
| 9    | 1.91679426 | 0.08290643 | 1.37031066 | 16.5283999 |
| 10   | 0.9423191 | 0.04035780 | 0.66954633 | 16.4274396 |
| 11   | 2.64451225 | 0.11438216 | 1.8946405 | 16.5625918 |
| 12   | 2.64451225 | 0.11438216 | 1.8946405 | 16.5625918 |
| 13   | 1.36080174 | 0.05885828 | 0.9690927 | 16.4648490 |
| 14   | 0.44416837 | 0.01922146 | 0.31532210 | 16.4132226 |
| 15   | 0.44416837 | 0.01922146 | 0.31532210 | 16.4132226 |
| 16   | 1.36080174 | 0.05885828 | 0.9690927 | 16.4648490 |
Judge-2

In this example, in the saaty scale rating by the judge, 10 AMDs rank are categorized into five groups, from 1 to 9. (Tables 5, 6 and 7).

| Groups          | D1   | D2   | D3   | D4   | D5   |
|-----------------|------|------|------|------|------|
| AMDs            | 2.3  | 9.11,12 | 4.10,13,16 | 5.14,15,6.7 | 1.8  |
| Intensity of Importance | 1    | 3     | 5    | 7    | 9    |
| Reciprocal      | 1    | 0.33  | 0.2  | 0.14 | 0.11 |

Table 6 Pairwise Comparison matrix

| AMDs | 1 | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  |
|------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1    | 1 | 0.11| 0.11| 0.2 | 0.33| 0.33| 0.33| 1   | 0.14| 0.2 | 0.14| 0.14| 0.14| 0.14| 0.33| 0.33| 0.2 |
| 2    | 9 | 1   | 1   | 5   | 7   | 7   | 7   | 9   | 3   | 5   | 3   | 3   | 5   | 3   | 5   | 7   | 5   |
| 3    | 9 | 1   | 1   | 5   | 7   | 7   | 7   | 9   | 3   | 5   | 3   | 3   | 5   | 3   | 5   | 7   | 5   |
| 4    | 5 | 0.2 | 0.2 | 1   | 3   | 3   | 3   | 5   | 0.33| 1   | 0.33| 0.33| 1   | 3   | 3   | 1   |
| 5    | 3 | 0.14| 0.14| 0.33| 1   | 1   | 1   | 3   | 0.2 | 0.33| 0.2 | 0.2 | 0.33| 1   | 1   | 0.33|
| 6    | 3 | 0.14| 0.14| 0.33| 1   | 1   | 1   | 3   | 0.2 | 0.33| 0.2 | 0.2 | 0.33| 1   | 1   | 0.33|
| 7    | 3 | 0.14| 0.14| 0.33| 1   | 1   | 1   | 3   | 0.2 | 0.33| 0.2 | 0.2 | 0.33| 1   | 1   | 0.33|
| 8    | 1 | 0.11| 0.11| 0.2 | 0.33| 0.33| 0.33| 1   | 0.14| 0.2 | 0.14| 0.14| 0.2 | 0.14| 0.2 | 0.33| 0.33| 0.2 |
| 9    | 7 | 0.33| 0.33| 3   | 5   | 5   | 7   | 1   | 3   | 1   | 1   | 3   | 1   | 3   | 5   | 3   |
| 10   | 5 | 0.2 | 0.2 | 1   | 1   | 3   | 3   | 3   | 5   | 0.33| 1   | 0.33| 0.33| 1   | 3   | 3   | 1   |
| 11   | 7 | 0.33| 0.33| 3   | 5   | 5   | 7   | 1   | 3   | 1   | 1   | 3   | 1   | 3   | 5   | 3   |
| 12   | 7 | 0.33| 0.33| 3   | 5   | 5   | 7   | 1   | 3   | 1   | 1   | 3   | 1   | 3   | 5   | 3   |
| 13   | 5 | 0.2 | 0.2 | 1   | 3   | 3   | 3   | 3   | 5   | 0.33| 1   | 0.33| 0.33| 1   | 3   | 3   | 1   |
| 14   | 3 | 0.14| 0.14| 0.33| 1   | 1   | 1   | 3   | 0.2 | 0.33| 0.2 | 0.2 | 0.33| 1   | 1   | 0.33|
| 15   | 3 | 0.14| 0.14| 0.33| 1   | 1   | 1   | 3   | 0.2 | 0.33| 0.2 | 0.2 | 0.33| 1   | 1   | 0.33|
| 16   | 5 | 0.2 | 0.2 | 1   | 3   | 3   | 3   | 5   | 0.33| 1   | 0.33| 0.33| 1   | 3   | 3   | 1   |

Table 7 Calculations for priority weight (W) and eigenvector $\lambda_{max}$

| AMDs | SQR(P) | $\omega$ | $A\omega$ | $\lambda_{max}$ | $\lambda_{max} = \frac{A\omega}{\omega}$ |
|------|--------|----------|-----------|-----------------|-----------------------------------------|
| 1    | 0.25027698 | 0.01053413 | 0.18034246 | 17.1198120        |
| 2    | 4.44197579  | 0.18696240  | 3.19032015  | 17.0639662        |
| 3    | 4.44197579  | 0.18696240  | 3.19032015  | 17.0639662        |
| 4    | 1.1472026   | 0.04828566  | 0.79420693  | 16.4480881        |
| 5    | 0.50543546  | 0.02127373  | 0.34847135  | 16.3803535        |
| 6    | 0.50543546  | 0.02127373  | 0.34847135  | 16.3803535        |
| 7    | 0.50543546  | 0.02127373  | 0.34847135  | 16.3803535        |
| 8    | 0.25027698  | 0.01053413  | 0.18034246  | 17.1198120        |
| 9    | 2.41938808  | 0.10183181  | 1.68888656  | 16.5850523        |
| 10   | 1.1472026   | 0.04828566  | 0.79420693  | 16.4480881        |
| 11   | 2.41938808  | 0.10183181  | 1.68888656  | 16.5850523        |
| 12   | 2.41938808  | 0.10183181  | 1.68888656  | 16.5850523        |
| 13   | 1.1472026   | 0.04828566  | 0.79420693  | 16.4480881        |
| 14   | 0.50543546  | 0.02127373  | 0.34847135  | 16.3803535        |
| 15   | 0.50543546  | 0.02127373  | 0.34847135  | 16.3803535        |
| 16   | 1.1472026   | 0.04828566  | 0.79420693  | 16.4480881        |

$\sum \omega = 1$
3.1. Checking Consistency Ratio
Matrix is rejected if the consistency ratio is CR > 0.1. Matrix is compatible and therefore suitable as each matrix, CR < 0.1, therefore (Table 8). Based on the acceptability of the matrix CR < 0.1. Random Index (R.I.) for n=16 is 1.5978.

| Judges | $\lambda_{\text{max}}$ | Consistency Index (C.I.) = $\frac{\lambda_{\text{max}} - n}{n - 1}$ | Consistency Ratio (C. R.) = $\frac{C.I.}{R.I.}$ |
|--------|------------------------|------------------------------------------------|------------------------------------------------|
| Judge-1 | 17.20644481 | 0.08042965 | 0.05033775 |
| Judge-2 | 17.11981204 | 0.07465414 | 0.04672308 |

3.2. Effectiveness of AMDs
We perform multiplication of AMDs matrix by individual judges to determine the effectiveness of each AMD (Fig. 4, Table 9).

![Figure 3 Matrix multiplication](image)

| S. No | AMDs                  | Rank by ISM | Effectiveness by AHP (%) |
|-------|-----------------------|-------------|--------------------------|
| 1     | Responsive Supply Chain | 10          | 1.046444                 |
| 2     | Top management support | 1           | 19.23258                 |
| 3     | Training and Education | 2           | 17.03263                 |
| 4     | Customer response adoption | 6       | 4.452174                 |
| 5     | Concurrent engineering | 8           | 2.02426                  |
| 6     | Re-configurable layout | 7           | 2.463586                 |
| 7     | Appropriate Hardware | 7           | 2.463586                 |
| 8     | Rapid prototyping      | 9           | 1.211334                 |
| 9     | Organisational Culture | 4           | 9.236914                 |
| 10    | Customer Involvement   | 6           | 4.452174                 |
| 11    | Knowledgeable Workers | 3           | 10.8107                  |
| 12    | Employee involvement   | 3           | 10.8107                  |
| 13    | Proper database management | 5       | 5.357198                 |
| 14    | Automation             | 8           | 2.02426                  |
| 15    | Virtual Enterprise     | 8           | 2.02426                  |
| 16    | IT Integrations        | 5           | 5.357198                 |
4. Result and Discussion
Currently, any manufacturing company must embrace AM to succeed and fulfill consumer demand. The principal purpose of the analysis is to measure, contrary to the title which determines the efficacy of AMs through the use of AHP, the results of the ISM. There are four AMs in our efficiency quantification analysis that seriously impact the effective execution of AM with a large percentage of efficacy are top management support, training and education, knowledgeable workers and employee involvement.

5. Conclusion
The results achieved will contribute to implement AMs for the effective application of AM after achieving the percentage effectiveness of AMs. For the theoretical and administrative dimensions of AM the effects of AHP may be implied, as they help managers to remove AMs for proper functioning of AM by taking certain measures depending on the driver percentage effectiveness. This research further allows one to consider the principles and drivers of AM by applying diverse revisions methodologies such as ISM and AHP. A wide range of AM is available in future research directions as manufactures move towards creativity and personalization, and so AMs should be researched to execute AM successfully.

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