AgiFlex System: An Approach towards Unification of Agility and Flexibility Dimensions from Manufacturing Perspective

Abid Ali, Dr. Wasim Ahmed, Dr. Mirza Jahanzaib, Dr. Salman Husaain, Dr. Haris Aziz, Zahid Rasheed
Department of Industrial Engineering and Management Sciences
University of Engineering and Technology, Taxila, Pakistan

Abstract

Intensive Competition and rapid technology development in global market has left no space for competing manufacturer to harbour system inefficiencies. The stress confronted by manufacturing systems is comprised of production of variety of products with efficient on time deliveries, flawless quality and with smallest possible costs. To be alive in market manufacturing organizations need to improve their systems by making them flexible and agile. Maintaining the effectiveness of dedicated system along with the flexibility of job shop is the objective of new manufacturing paradigm. An effort is made through this paper to develop a hybrid system that contains both the attributes of flexibility and agility. Developed *AgiFlex* system is then experimented in discrete event simulation environment and evaluated against a real time manufacturing system. Results have shown that *AgiFlex* system accommodates expected and unexpected market changes swiftly by engaging its flexible and agile attributes simultaneously.

Keywords— AgiFlex, Agility, Flexibility, Manufacturing

1 Introduction

Ever changing market needs, enhanced competition and extremely uncertain environment have changed the manufacturing priorities. The manufacturing evolution has progressed from conventional manufacturing to flexible manufacturing and it is hovering over agile manufacturing now. Flexible manufacturing along with other manufacturing strategies like lean manufacturing have efficiently served the manufacturers. Even now, these strategies are moving the manufacturing world on. In recent past the need of organizations to be agile and flexible has emerged due to unexpected customer demands, growing need of prompt deliveries and shorter product life cycles. To accommodate and serve these needs well a system is require which is flexible and responsive at the same time. Many organizations have faced tremendous disasters due to inability to take up the emerging needs of customers and others have flourished who responded quickly to unexpected changes and customer needs. Which manufacturing strategy or which manufacturing system is way to the survival is burning question in the business world. In manufacturing viewpoint flexibility and agility are highly debated manufacturing approaches. Flexible manufacturing system attracted the manufacturers but now they are staring at the agile manufacturing in hope of finding it as complete package to fulfil their market needs. Flexibility in practice is applied at manufacturing process level and deals with predetermined varieties of products and predetermined responses towards expected market changes. But it does not cope well with sudden unexpected marked changes as it is process focused. Agile manufacturing on the other hand, focuses a little bigger picture. Agility deals with system design such that it can absorb unexpected market changes. Agility being proactive in natures addresses the strategic issue of responsiveness. So the need of a system strengthens which can deal with both process level consideration and requirements at system level. AgiFlex is a manufacturing system carrying both the attributes of flexibility and agility to deal with expected and unexpected market changes. AgiFlex is designed by extracting the resembling attributes of agility and flexibility then it is compared with real manufacturing system of a exporting manufacturing SME by means of exercising it in a simulation environment. Results are statistically evaluated which endorse that the AgiFlex system should be taken as new manufacturing structure to excel in global market.

2 Literature Review

The literature dedicated to both concepts of flexibility and agility is explored in following lines. Flexibility and agility are investigated at first followed by the discussion on commonalities and differences of both.

The concept of providing variety of products through flexible manufacturing processes in high volumes at lowest possible cost emerged in late 1980s.The flexible manufacturing, after decades of research, appears to be

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an alternative to different companies in competitive and fragmented market. Competition in manufacturing industries in upcoming decade would be focused on flexibility and quick response to the market changes. Manufacture giants have discovered that producing in high volume for mass market is no more the way to stay in business [1]. The flexible manufacturing system covers a wide variety of automated manufacturing system it basically consists of CNC machines, material handling system and a controlling mechanism [2] .Manufacturing flexibility is the ability of manufacturing system to adapt with uncertain environments and it can be a competitive concern [3][4] but gaining flexibility has cost associated with it [5] and must be appreciated [6]. Different types of flexibility such as product mix flexibility, process flexibility and volume flexibility can be defined respectively as ability to manufacture several products without major setup costs, having different process designs and routing and being able to manufacture at different output levels [7] [8].

Businesses are reorganizing and restructuring themselves in reaction to the challenges and uncertain demands of the 21st century. The business of 21st century will have to overcome the challenges of customer's requirements of high quality, low cost products and responsiveness to ever changing customer needs [9. Over the past two hundred years the evolution and development of manufacturing methodologies can be summarized in major four categories that are, pre-industrial revolution, industrial revolution, lean manufacturing and flexible manufacturing [10]. A novel manufacturing methodology, emerged as agile manufacturing, is considered to be a replacement of present industrial paradigm.

Agility is defined in various ways in the literature, such as the capability of an organization to respond swiftly to unforeseen opportunities and to develop solutions for potential needs in a proactive manner [11]. Agility means to be capable of adopting changes and allowing an organization what it wants to do and whenever it wants to do [12]. [13] Presented agility design principles having attributes of re-configurability, reusability and adoptability. In the past, the strategy of economies of scale prevailed in the manufacturing world and people focused on mass production and full utilization of plants to make profits. This was done by sacrificing the flexibility in manufacturing because those plants and manufacturing setups were never easy to reconfigure. Some authors contrast the agile and flexible manufacturing. The flexible manufacturing is a reactive approach whereas agile manufacturing is proactive strategy [14]. Others bracket together agile manufacturing with lean manufacturing. [15] Differentiates both by unfolding lean as set of operational techniques dedicated towards productive use of resources whereas agility has an attribute of thriving for uncertain environments. According to [16] the companies who want to become market leaders must speed up its transition to agile manufacturing. Agility is broadly categorized in agility of product design, agility of process design, agility of material handling system, agility of process planning and agility of facility design and location. Agile manufacturing is a strong step towards the solution of the manufacturing enterprises with dynamic and unpredictable market changes [17]. A vast literature deals the concern of similarities and differences in both manufacturing philosophies (Table 1).

Table 1 Comparison of Agility and Flexibility

Similarities and Differences	Agility	Flexibility
Copes with unexpected changes	√	×
Ability to be profitable tomorrow	√	×
Is applicable at strategic level	√	×
Emphasis on system	√	×
Is a proactive approach	√	×
Focuses directly on customers	√	×
Is applicable at design stage	√	×
Copes only with expected changes	×	√
Ability to be profitable today	×	√
Is applicable at process level	×	√
Emphasis on resources	×	√
Is a reactive approach	×	√
Focuses indirectly on customers	×	√
Is applicable on execution stage	×	√
Focuses on changes in customer demands	√	√
Enables to be profitable in uncertainties	√	√
Takes input from forecasting	√	√
Has potential of adaptability	√	√

At system and resource level there is clear distinction between agility and flexibility. Many authors tried to resolve the issues regarding comparison of agility and flexibility. The real difference lies at the level of application. The agility is mainly focused on strategic level whereas flexibility is related to operational level [15].

A great deal of literature is dedicated to the flexible and agile manufacturing and even more literature is focused on the debate of either these two approaches differs or they are similar. Both manufacturing strategies differ in their level of implementation. No effort is yet made to hybridize both strategies. There are only outlined concepts of combing flexibility and agility theoretically but practical designing and implementation of hybrid system of flexibility and agility is yet missing. AgiFlex manufacturing system is a novel development which is implemented in simulated manufacturing environment and justified with its outputs.

3 Methodology Adopted

To investigate and develop systems, various models are used. Physical models, analytical models, expert systems and discrete even simulation are those means that can be used to study any system. Physical models are not practical in context of all manufacturing systems because it's literally impossible to construct a physical model in tangible form to experiment your concepts. Analytical models have their own limitations of need of so many assumptions. As the system's complexity grows analytical model effectiveness reduces. Expert systems need a huge knowledge base and then it's interpretation in to rules that is also very time consuming activity. Simulation modelling offers a very flexible platform to probe into the system and to experiment various configurations very easily. That is why discrete event simulation is used as a means of development of AgiFlex model.

From last 40 years simulation tool has widely been used for design and analysis of manufacturing systems. During this era, simulation has established itself as an extremely handy analysis tool [18] .Simulation involves the development of illustrative computer models of a system and working out those models to foresee the operational performance of the underlying modelled system. Performing a simulation analysis can ultimately disclose discrepancies between a professional's comprehension of operations and the real system. It also facilitates to identify chances to improve data collection for use in potential process improvement ventures [19]. Simulation for flexible manufacturing system design and operation has established a marvellous amount of consideration in the research literature. The inherent flexibility of flexible manufacturing system makes the analysis and design of such systems extremely complex and intricate [20]. It is this complexity that makes simulation an attractive design and analysis tool in this domain. The first who employed simulation study for flexible manufacturing systems is Week [21][22].

It is established that conventional planning means and mathematical/analytical modelling practices are not appropriate if comprehensive investigation is required for complex manufacturing systems. Modern manufacturing systems comprise of numerous discrete processes that take place at random and at non-linear way so the mathematical models or other technique are seldom realistic. Among all these complexities, simulation modelling in the form of discrete event simulation has developed to become one of the most accepted and cost-effective means of examining intricate systems [23].

SIMIO the world best discrete event simulation software is was selected to carry out experimentation. The selection is made after going through the software selection procedure [24].

There are about 200 simulation tools available in market. This is very essential both for a company and simulation specialist to know the world best or at least most popular simulation tool. This is equally important for education institutes to approach one of the best simulation tools for their students because the students are the future simulation specialists. The ranking starts with removing of the continuous simulation tools from the list. [25] Studied and evaluated 19 discrete event simulation tools against 40 parameters. SIMIO was ranked as world best and most popular discrete event simulation tool.

4 Development of Model

To carry out simulation study and to prepare model of any system the type of probability distribution for each activity is required. The statistical data of processing times of each station of real manufacturing process were gathered and then using distribution fitting software (Expertfit) probability distributions for processing time of each station were estimated. Table 2 presents the processing time of each station in the form of its probability distribution.

4.1 Simulation Results (Existing Configuration)

The simulation model of existing manufacturing process is run for three weeks, 180 hours, ten hours per day (warm up period is not included). The average throughput was observed after completion of simulation runs. The throughput estimated by simulation model is different from the throughput calculated by analytical models the reason of difference is the stochastic nature of the simulation modelling. Also in analytical models the mean time is given as input whereas in simulation the time is given in form of probability distributions. Simulation results for throughput of existing system are as follows.

1073 pc per day, 107 pc per hour

Table 2 Probability distributions for each station

Sr .No	Workstations	Distribution Types (Time in seconds)
1	Tube Cutting Station	Random. Gamma(5.86817,0.61738,3.11123)
2	Tube Closing Station	Random. Gamma(3.91057, 1.00677, 1.81656) Random. Gamma(5.18322, 0.69143, 4.59205)
3	Welding Station	Random. Lognormal(1.1854,0.51928,0.42323) Random. Gamma(1.88707,0.47267,5.50003)
4	Leakage Testing Station	Random. Gamma(4.9429,0.70636, 4.79264)
5	Spring Making Station	Random. Gamma(18.13678, 0.01942, 2.38278)
6	Filling Station	Random. Weibull(5.08095, 2.25022, 2.32748) Random. Gamma(3.16281, 0.36072, 4.2115)
7	Weight Testing Station	Random. Gamma(2.89181, 1.55176, 1.52768)
8	Continuity Testing Station	Random. Gamma(2.89181, 1.55176, 1.52768)
9	Reducing Station	Random. Exponential(0.09163)
10	Marking Station	Random. Gamma(4.89051, 0.72702, 1.69222)
11	Annealing Station	Random. Gamma(5.03553,0.24037,2.62116)
12	Bending Station	Random. Gamma(3.77457,0.83565, 3.31983)
13	Demoisturizing Station	Random. Gamma(4.89051, 0.72702, 1.69222)
14	Continuity Testing Station2	Random. Gamma(2.89181,1.55176, 1.52768)
15	Fitting Station	Random. Exponential(0.05489)
16	Brazing Station	Random. Weibull(0.38718, 4.15789, 2.83579) Random. Weibull(16.33684,18.81482, 3.52829)
17	Pressure Testing Station	Random. Gamma(1.77952, 0.18888, 12.68282) Random. Weibull(2.77675,12.02979, 6.06304)
18	Epoxy Filling Station	Random. Normal(1.59778, 0.24321) Random. Normal(8.28796, 0.62893)
19	Microiline Testing Station	Random. Triangular(24.05542,32.46,43.84337)
20	Holder Attachment Station	Random. Gamma(8.01129, 1.0016, 1.72913)
21	Cleaning Station	Random. Triangular(4.45986, 10.4, 18.43034)
22	Thermostat Assembly Station	Random. Normal(11.13391,1.98951)
23	MFT Station	Random. Normal(27.23409, 3.84709)
24	Packaging Station	Random. Uniform(36.68654, 56.38346)

Statistical Analysis of Simulation Outputs

For output analysis of steady state simulations two parameters are considered.

- Warm-up period
- Number of replications

The warm up period for simulation run is estimated by analysing the target output. The period in which the under consideration parameter get its steady state is determined as warm up period and this period is then excluded while recording observations. Our simulation model gets its steady state in less than 4 hours but for more accuracy the warm up period was decide as 5 hours. The warm up time and final run length must follow the relation of equation (1).

L=10d **(1)**

L is length of total simulation run. d is warm up period

To initiate the output analysis of the simulation results 10 replications were made initially and the throughput of each random replication was recorded. The half width was calculated at 99% confidence interval. That came to be 0.81. **n=10,**$\alpha = 1$

$t_{9,.995} = 3.250$. The percentage error is estimated by employing interval half width that is 0.081. Ten initial simulation replications were made to estimate the required number of replications for final analysis. For ten data points standard deviation and average were 0.943 and 1074 respectively.

The greater the number of replications lesser is the percentage of error. If infinity of the replications are made the error will approach to zero. Of course to perform infinity of the replications practically and economically is impossible. The numbers of replications that can reduce the error at maximum while keeping the constraints of time and resources intact are needed. As one increases the replications the error percentage starts decreasing and a stages comes when increase in replications effects very little to the percentage of error. That means at that point more effort has to put in form of replications to lower the error a little. In our experiment that stage reached when number of replication crossed number 80, but for more precision in results 100 replications were decided for final analysis. Figure 1 shows the detail.

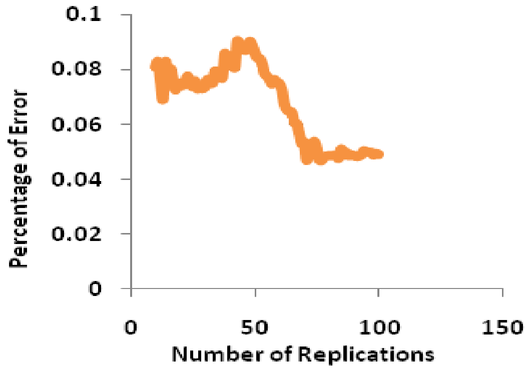

Figure 1 behaviour of percentage of error with respect to number of replications

Statistical Verification of Output of Simulation Model

As the simulation models utilize stochastic data comprising of random probability distributions so the need of model verification intensifies. And questions is raised how much we can rely on the output of simulation model that entirely depending on random data values. Statistical verification of output results of simulation are necessary to establish a trust on the outputs because important decisions are to be taken by just relying on the results of simulation. Important question is that either the built model reflects the real system or not? To address this question the statistical verification is required.

Paired Comparison t- Test

The acceptance of simulation results is conditional with its statistical verification. Either constructed simulation model reflects the real system or not, this fact is required to be analysed and validated statistically. In this regard the sample means of both real system and simulated system are needed to be examined for deduction of inferences. The size of sample taken from each system and its mean and standard deviation are presented in Table 3.

Table 3 Sample means of both system

	Mean	**SD**	**Sample Size (n)**
Real System	1072	2.55	100
Simulation Model	1073	2.20	100

Inferential statistics facilitates the researchers to infer about very large populations by employing small sample sizes because those samples belong to the population. Either its controlled experiments or it's an observational study the probabilities are involved. We used observational data to construct simulation model and then modified model was built by controlling the parameters. The results of simulations are to be statistically validated before its utilization. Because the simulation study involves probability distributions so results are prone to doubts if not statistically validated. For that purpose hypothesis testing is essential to gain trust on output results. Following notations are use in next calculations

$\boldsymbol{H_0}$ Null Hypothesis, $\boldsymbol{H_a}$ Alternate Hypothesis. $\boldsymbol{\bar{x}_1, \mu_1}$ Sample mean of simulated system throughput. $\boldsymbol{\bar{x}_2}$, $\boldsymbol{\mu_2}$, Sample mean of real system throughput. $\boldsymbol{s_1}$ Sample standard deviation of simulated system. $\boldsymbol{s_2}$ Sample standard deviation of real system. $\boldsymbol{n_1}$ Size of sample taken from simulated system. $\boldsymbol{n_2}$ Size of sample taken from real system

Constructing the Hypothesis To draw conclusion about the validity of model null and alternate hypothesis are constructed as under. $\alpha = .05$

$$\boldsymbol{H_0} : \boldsymbol{\mu_1} - \boldsymbol{\mu_2} \geq 0$$

$$\boldsymbol{H_a} : \boldsymbol{\mu_1} - \boldsymbol{\mu_2} < 0$$

Significance level of .05 is used in the calculations of hypothesis testing. The margin of error is .66 at confidence interval of 95%.

Hypothesis testing

Value of D_0 = Hypothesized difference between two means is taken as 0 in above calculations. $\boldsymbol{t}$ =2.96 and degree of freedom is $df = 194$.

p value and decision of hypothesis

At 194 degree of freedom with t value of 2.96 (Appendix A) denotes the estimation of $\boldsymbol{p}$ value. The black arrow points the value- $\boldsymbol{p}$.

$$\boldsymbol{p\ value} < \alpha, \boldsymbol{\alpha} = .\mathbf{05}$$

The value- $\boldsymbol{p}$ which is less than α supports the *rejection of Null hypothesis* and acceptance of alternate hypothesis, hence it can be concluded that the output of both systems, simulated and real, is identical. And the simulated model truly reflects the real system so the model can be used and the outputs of the simulated system would be reliable.

4.2 Proposed Manufacturing Process

Sizing the Manufacturing Process

In the course of balancing the process the servers are added in proposed manufacturing setup to balance the work load and to remove the *bottlenecks*. In the course of *balancing* the system total *twelve servers* are added out of which nine are machines and three are workers. Along with the additional marking station is removed as it is merged with the annealing station.

The simulation model of proposed manufacturing process is run for three weeks, 180 hours (excluding warm up period), ten hours per day. The average throughput was observed after completion of simulation runs. The throughput estimated by simulation model is different from the throughput calculated by analytical models the reason of difference is the stochastic nature of the simulation modelling. Also in proposed configuration through analytical models the *mean* time is given as input whereas in simulation the time is given in form of probability distributions. Simulation results for throughput of existing system are 3168 pc per day that is 317 pc per hour.

Outputs of Proposed Process

For statistical analysis of proposed simulation outputs of the same procedure is adopted which is carried out for outputs of simulation model of existing configuration.

- Warm up time 5 hours
- Run length 180 hours

The 99 % confidence interval half width for ten initial replications was estimated 16.99 with percentage error of 0.53. The mean and standard deviation of ten data values is 3174 and 15.67 respectively.

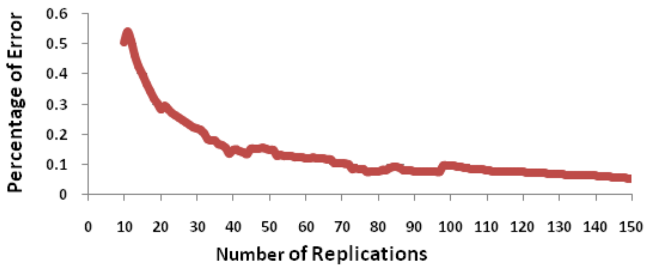

Figure 2 Error percentages as function of number of replications

The figure 2 demonstrates that number of replication and percentage of error are negatively correlated. The greater the number of replications lesser is the percentage of error. If infinity of the replications are made the error will approach to zero. Of course to perform infinity of the replications practically and economically is impossible. The numbers of replications that can reduce the error at maximum while keeping the constraints of time and resources intact are needed.

As one increases the replications the error percentage starts decreasing and a stages comes when increase in replications effects very little to the percentage of error. That means at that point more effort has to put in form of replications to lower the error a little. In this model while experimenting, that stage approximately reached when number of replication crossed number 140, but for more precision in results 150 replications were decided for final analysis. Throughputs of 150 replications are not shown due to space restrictions.

Statistical Verification of Results (Proposed Manufacturing Configuration at Process level)

The sample of hundred values is collected from both existing and proposed systems outputs, i.e. throughputs. Mean value, standard deviation and sample size is presented in table 4.

Table 4 Sample Means of Throughputs of Proposed and Existing process

	Mean	SD	Sample Size (n)
Real System	1072	2.55	100
Proposed System	3168	11.8	100

Hypothesis Testing

To draw conclusion about the validity of proposed model null and alternate hypothesis are constructed as under.

$$H_0 : \mu_1 - \mu_2 \leq D_0$$

$$H_a : \mu_1 - \mu_2 > D_0$$

$$D_0 = 2092 \; \alpha = .05$$

Hypothesized difference of both means is taken as 2092. Hypothesis is tested for the difference which is even greater than hypothesized difference. The rejection of Null hypothesis with hypothesized value of 2092 will give more trust on the proposed model output.

The value of $\boldsymbol{Df}$ and t value$df = 109$, $t =$3.31 are respectively.

With degree of freedom 109 and **t-value 3.31** the $\boldsymbol{p}$-value is estimated (Appendix B).

$p - value \cong 0.0005$ Which is less than $\alpha, 0.05$ as$p < \alpha$, hence null hypothesis is rejected. Alternatively alternate hypothesis is accepted, that simply means the throughput of proposed Process is greater than existing system by value of 2092.

5. Incorporating Agility and Flexibility Simultaneously

In previous discussion it is noted that flexibility and agility are different in level of application. The flexibility being narrow in scope is applied at process level. The process of manufacturing of electric element is investigated and by reconfiguring the process throughput of system and utilization of the resources is improved. Even with reconfigured process the SME is not yet flexible enough to absorb uncertain and unexpected changes. To make the system which can accommodate unexpected changes the agility is to be incorporated at design level. It is to be worth mentioning here that the term "system" used has different meaning than term "process" used previously. Process represents the manufacturing process only whereas system covers whole enterprise.

5.1 An AgiFlex System

Sizing of the manufacturing system has made it enough flexible to accommodate expected changes like variation in demand and variation is quantity of product mixes. These are expected uncertain changes which can be accommodated by flexibility at manufacturing process level. The unexpected market changes are not addressed yet. Following scenarios are faced by any manufacturing system. The system which can accommodate situations of all these scenarios can be termed as AgiFlex system.

1st Scenario: Regular demand with no design changes

This is very usual situation when manufacturing system faces only changes in quantity demanded and no changes in design of product are required by customers. The system working under this scenario is just a conventional system.

2nd Scenario: Demand with minor design changes

Minor changes in product design are normally demanded by customers which commonly include little changes in dimensions, colour or alteration of few components. The manufacturing system working under 2nd scenario along with 1st has very limited flexibility at process level . It is to be worth mentioning that first two scenarios are fulfilled by sizing the manufacturing process. The remaining three scenarios need an AgiFlex structure to be dealt with.

3rd Scenario: Demand with major design changes

System would be flexible if it can cope with major design changes and can produce predetermined variety of products. Major changes include changes in core components of any product.

4th Scenario: Demand of completely new product (Product is new to company)

In this scenario manufacturing system is confronted with demand of products that is new to market and does not exist in the list of company. The system absorbing the uncertainties of 4th scenario along with demands of first three scenarios would be fully flexible but restricted agile.

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5th Scenario: Demand of innovative product (Product is new to market)

Finally how manufacturing system translates innovative idea into reality and how quickly respond to demands of customers which are creative in nature decides the ability of system to be an AgiFlex system. The manufacturing system which can cope with demands of all these five scenarios would be AgiFlex system. First two scenarios are evaluated in above discussion of proposing the new process by sizing the manufacturing system at process level. Last three scenarios are subjects of agility and would be dealt with in following lines

The probability distributions along with times in number of days are collected by consulting experts. Each activity is allocated different duration depending on its nature. First two scenarios are modelled at process level and remaining three are simulated at system or strategic level.

The proposed model of AgiFlex presents all five scenarios confronted by any manufacturing system. The approach corresponding to each of the scenario is outlined and designated separate colours. The scenarios listed above are arranged from left to right. Scenario one follows the light black blocks from decision block to material testing block. 2nd and 3rd scenarios are comprised of green and purple blocks respectively. 4th and 5th scenarios which are core of agility are described in pink and orange colours respectively.

Furthermore the simulation structure of AgiFlex with all its components. Product demands of 3rd, 4thand 5th scenarios follow lower, middle and upper stream respectively. These products follow their specified sequences until completion. The two right most block streams truly deals with the agility.

5.2 AgiFlex System: Simulation Outputs

At start of analysis 10 replications are made to take a rough guess of performance parameters. The value of interval half width and percentage of error are estimated along with the mean and standard deviation of sample data (Table 5).

P1, products with major changes in design
P2, products that are new to enterprise/company
P3, products that are new to market

Table 5 AgiFlex system throughputs in three years

Replication No.	P1 Throughput	P2 Throughput	P3 throughput
1	94	38	16
2	93	37	14
3	92	37	15
4	95	39	16
5	94	38	16
6	94	37	16
7	95	37	16
8	93	39	18
9	94	36	17
10	93	38	15
SD	*0.948*	*0.96*	*1.1*
Average	*93.7*	*37.6*	*15.9*
h.99	*0.96*	*0.97*	*1.11*
% of Error	*0.1.02*	*2.6*	*7.0*

For output analysis of steady state simulations two parameters are considered. That is Warm-up period and Number of replications. The warm up period for simulation run is estimated by analysing the target output. The period in which the under consideration parameter get its steady state is determined as warm up period and this period is then excluded while recording observations. AgiFlex model gets its steady state in less than 3.5 months but for more accuracy the warm up period was decide as 3.6 months. The warm up time and final run length follows the relation of equation (1).

L= 10d, d is length of warm up period and L is total run length

The simulation run length is decided 3 years i.e. 36 months (greater than $10d$). The number of replications affects the percentage of error as described in previous discussions. Greater the number of replications lesser will be the percentage of error. The various number of replications are tried to get an estimate of reduction in percentage of error. During experimentation the percentage of error reduced as replications increased. The replication number where percentage of error was reasonably low and became steady, figure 3 was decided as final number of replications. Hundred replications are decided for AgiFlex simulation run.

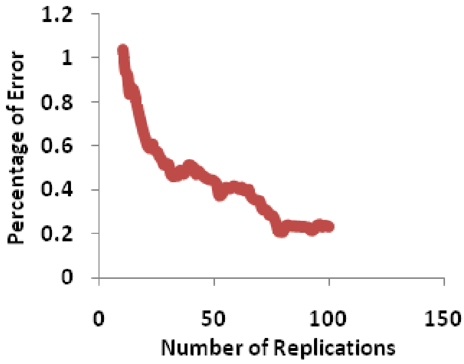

Figure 3 Percentage of error as function of number of replications (AgiFlex System)

5.3 Versatility of AgiFlex

Simulation results show the creation of diverse product by AgiFlex system in a certain period of time. As the system possesses both the attributes of flexibility and agility it can confront expected and unexpected demand changes. Table 17 shows production of various products in period of three years (excluding large scale production). In addition to regular products and products with minor design changes the ***AgiFlex*** created 94 products with major design changes, 38 new products (new to company) and 16 innovative products which were new to market. *It is to be noted the quantity 94, 38 and 16 is in terms of variety of products not in terms of volume of production*. E.g. total 16 different innovative products were created at various times in three years, once the product is created its joins the mass production stream straightway. Table 6 is tabulated with responses to uncertain customer's demands by ***AgiFlex***.

Table 6 New Products included in the list in three years

AgiFlex's Versatile Throughput to meet unexpected demands		
P1 Throughput	**P2 Throughput**	**P3 Throughput**
94	39	17

5.4 AgiFlex Index

To assess the level of agility and flexibility in a manufacturing system the AgiFlex index is developed. The ***AFI*** calculates the level of flexibility and agility by estimating the different agility and flexibility parameters. Flexibility and responsiveness of system is directly proportional to the agility index.

$$AFI = \frac{0*\bar{P}_{nd}}{\bar{t}_{nd}} + \frac{0.4*\bar{P}_{mnd}}{\bar{t}_{mnd}} + \frac{\bar{P}_{mjd}}{\bar{t}_{mjd}} + \frac{2*\bar{P}_{nc}}{\bar{t}_{nc}} + \frac{4*\bar{P}_{nm}}{\bar{t}_{nm}}^{3} \qquad \textbf{(2)}$$

$\bar{P}_{nd}, \bar{P}_{mnd}, \bar{P}_{mjd}, \bar{P}_{nc}, \bar{P}_{nm}, \bar{t}$ are Average number of products with *no design* changes, *minor design* changes, *major design* changes, *new to company, new to market and* per year respectively and $\bar{t}$ is their respective average time to market.

AFI of Existing System

The existing system is producing products whose demand is stable and less prone to uncertainties. Along with the smooth demands the products with minor design changes are also being produced.

$$AFI = 0 + \frac{0.4*60}{1} + 0 + 0 + 0$$

$\boldsymbol{AFI} \approx 24$

The AFI number below 30 denotes that the system has a little flexibility to accommodate minor changes in product design but unable to deal with bigger changes in product features and also it is handicap towards innovative products.

AFI of AgiFlex System

By applying equation (2) AFI is calculated as under.

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$$AFI = 0 + \frac{0.4*60}{1} + \frac{31}{10} + \frac{2*13}{24} + \frac{4*(6)^3}{50}$$

AFI ≈ 45

The above value of ***AFI*** predicts the responsiveness and flexibility of AgiFlex system. The value above 30 shows that the system can cope with expected unexpected changes in customer demands (figure 4).

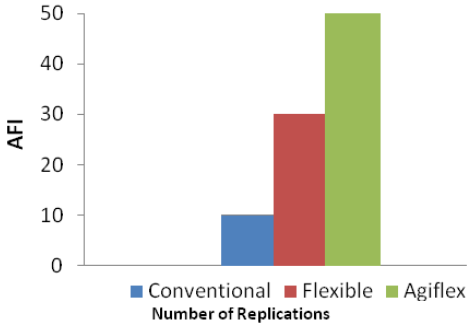

Figure 4 Nature of system and respective *AFI*

Table 7 presents the *AFI* data of past 10 years of existing system and data of 10 replications of AgiFlex system.

Paired comparison t-Test

To statistically verify the difference between the means of ***AFI,*** t-test is to be done. The required sample data of existing system ***AFI*** and AgiFlex system ***AFI*** along with sample means and standard deviations is tabulated in table 8.

Table7 AFI data of both systems

Years	AFI (Existing System)	AFI (AgiFlex)
1	23	43
2	24	43
3	25	46
4	24	46
5	25	46
6	24	44
7	23	46
8	23	45
9	24	44
10	23	44
Average	*23.8*	*44.7*
SD	*0.788810638*	*1.18743421*
n	*10*	*10*

Paired Comparison t-Test and Hypothesis Testing

$$H_0 : \mu_1 - \mu_2 < D_0$$

$$H_a : \mu_1 - \mu_2 > D_0$$

Ho, Null hypothesis states that the difference between mean values of ***AFI*** of both samples is less than Do=0, that mean there is no difference in the AgiFlex index of existing system and AgiFlex index of AgiFlex system. If null hypothesis cannot be rejected then the conclusion would be drawn that there is no difference between existing and proposed system in terms of flexibility and agility.

Ha, Alternate hypothesis in contrast to the null hypothesis seeks the difference in means of AgiFlex index of given samples. That means if alternate hypothesis is accepted at given significance level then with confidence it can be concluded that both systems differ in terms of flexibility and agility.

Df =16 ***t***=47

The critical t-value is minimum t-value needed to have

$p < \alpha, .05$

The critical t-value for the test is 2.5.The calculated t-value is far greater than the critical t-value i.e. 47. As larger t-value translates into smaller **p** values so larger is the t-value more likely the difference is significant. So logically the p-value for above hypothesis is less than **α 0.05** hence the null hypothesis is rejected. The acceptance of alternate hypothesis leads to the conclusion that mean ***AFI*** value of AgiFlex is greater than mean ***AFI*** value of existing system. A system with greater AgiFlex Index leads to the system which is more flexible, agile and responsive at the same time.

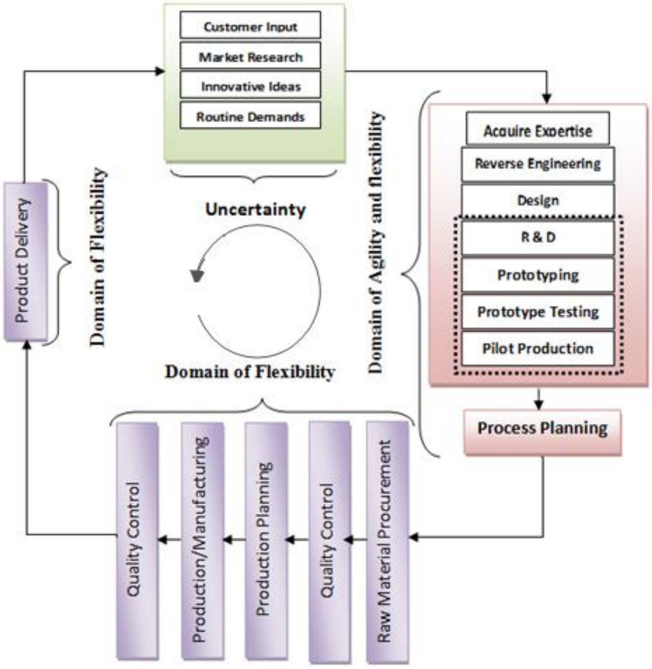

Figure 5 AgiFlex Cycle

AgiFlex Cycle, figure 5, starts by taking input from an uncertain environment which comprised of customer inputs, market research, innovative ideas, routine demands, and consumers in particular. The nature of the demand then decides respective course of action. The demands generated by these inputs are transmitted to respective functional heads. By going through designing, research and development, process planning, production and quality checks the demands are delivered to the customers and this cycle keeps on moving and exploring.

6. Conclusion

In this paper an effort is made to develop an AgiFlex system for manufacturing by simultaneous implementation of agility and flexibility in practitioner's perspective. The commonalities and differences of both agility and flexibility are undertaken by putting both theories in practice. Agility and flexibility are combined to evolve a paradigm in which flexibility becomes a platform to foster agility. By exploiting the fact of being harmonizing to each other both concepts are assorted to craft an *AgiFlex* system which increased the throughput at process level and accommodated uncertainties at system level. As a pilot study, model of AgiFlex system is implemented, in simulation environment, in an exporting SME. Findings support the fact that unification of agility and flexibility lead to smaller time to market, extensive product variety and increased throughputs. ***AgiFlex Index*** is developed which is function of ability to fulfil unexpected demands and time to market of product. Outputs of AgiFlex system and its statistical verifications against existing system outputs make *AgiFlex* system a milestone for future manufacturing. The developed system being more versatile and flexible copes with unexpected demands of variety of products along with keeping regular processes intact. Results showed that *AgiFlex* system with hybrid attributes of agility and flexibility is more responsive towards uncertainties by its built in predetermined as well as innovative responses.

REFERENCES

[1] B. Fulkerson "A Response to Dynamic Change in the Market Place" Journal of Decision Support Systems 3 (1997) pp. 199-214.
[2] R. D. Sidhartha, C. Cem "An algorithm for scheduling batches of parts in a multi-cell flexible manufacturing system" Int. J. Production Economics 97 (2005) 247–262.

[3] H. L. Correa "Linking flexibility, uncertainty and variability in manufacturing systems" Avebury Business School Library (1994) pp. 198.
[4] C.H Fine, A.C. Hax "A. Manufacturing strategy: a methodology and an illustration" Interfaces 15(6) (1985) 28-46.
[5] A.K. Sethi, S.P. Sethi "Flexibility in manufacturing: a survey". The International Journal of Flexible Manufacturing Systems. 2 (**1990**) pp. 289-328.
[6] R. Pellegrino "Evaluating the expansion flexibility of flexible manufacturing systems in uncertain environments". International Journal of Engineering Management and Economics Vol. 1(2) (2010) pp145-161.
[7] J. Browne, D. Dubois, K. Rathmill, S.P. Sethi, K.E. Stecke. "Classification of flexible manufacturing systems". The FMS Magazine 2(2) (1984) pp.114–117.
[8] D. Fontes. Fixed versus flexible production systems: a real options analysis. European Journal of Operational Research 188(1) (2008) pp.169-184.
[9] P. Bunce, P. Gould , "From Lean to Agile Manufacturing". IEE Colloquium (Digest), No. 278 (1996) pp. 3/1±3/5.
[10] J. Mark Hooper, D. Steeple "Agile Manufacturing - Manufacturing for the New Millennium - A Critical Review" International Conference on Management and Technology (1997) pp.635 - 637.
[11] A. Nelson, F.A Harvey. "Technologies for Training and Supporting Your Agile Workforce. In: Creating the Agile Organization: Models, Metrics and Pilots". Proceedings 4th Agility Forum Annual Conference. Agility Forum, Bethlehem March 7-9 (1995)
[12] R. Dove "The Meaning of Life and the Meaning of Agile" Production Magazine (1994).
[13] R. Dove, "Design principles for agile production" Production Magazine 107(12) (1995) pp. 16-18.
[14] C. W. Richards "Agile manufacturing: Beyond lean?" Production and Inventory Management Journal 37 (1996) pp60-64.
[15] S. L. Goldman, R. N. Nagel, and K. Preiss "Agile Competitors and Virtual Organizations: Strategies for Enriching the Customer" New York, NY: Van Nostrand Reinhold (1994).
[16] N. Roger, R. Dove 21st Century Manufacturing Enterprise Strategy Report, 21st Century Manufacturing Enterprise Strategy an Industry Led View.
[17] L.M. Sanchezy and R.Nagi "A review of agile manufacturing systems" IJPR 39(6) (2001) pp. 3561-3600.
[18] J. S. Smith "Survey on Use of Simulation for the Manufacturing System Design and Operation" journal of manufacturing systems 22(2) (2003) pp. 157-171
[19] P. Andreas, B. Steven "A rapid modelling technique for measurable improvements in factory performance". Proceedings of the 1998, 38tWinter Simulation Conference, Washington, DC, (1998). pp. 1011–1016
[20] Y. Chang, R.S. Sullivan, J.R Wilson "Using SLAM to design the material handling system of a flexible manufacturing system." Int. Journal of Production Research v24(1) (1986) pp15-26.
[21] M. Week, A. Schuring. "What aids are available for the design and development of computer controlled manufacturing systems." Proc. Of NAMRC Vol.3 (1975) P. 751.
[22] G.K. Hutchinson, B.E. Wynne, "A flexible manufacturing system" Industrial Engg. Vol 5(12) (1973) pp. 10-17.
[23] K. Rathmill, N. Greenwood, M. Housmann "Computer simulation of FMS" Proceedings of the Second International Conference on Flexible Manufacturing Systems, (1983) pp. 251±280.
[24] Vlatka Hlupic and Ray J Paul "Methodological approach to manufacturing simulation software selection" journal of Computer Integrated Manufacturing Systems. Vol 9(1) (1996) pp.49-55.
[25] M.S Dias , A.B Pereira, V Pavel; A . Jose "Discrete Simulation Tools Ranking: a Commercial Software Packages Comparison Based on Popularity" Publisher Eurosis (2011).

Appendix A

t Table df	0.1	0.05	0.02	0.01	0.005	0.002	0.001
193	1.6528	1.9723	2.3458	2.6015	2.8397	3.1330	3.3417
194	1.6528	1.9723	2.3457	2.6014	2.8395	3.1328	3.3414

(Partial view of t table)

Appendix B

t Table	0.1	0.05	0.02	0.01	0.005	0.002	0.001
108	1.6591	1.9822	2.3614	2.6221	2.8658	3.1674	3.3829
109	1.6589	1.9820	2.3611	2.6217	2.8653	3.1667	3.3820

(Partial view of *t* table)