The Effect of Machine Layout on Engine Block Manufacturing System Profitability and Rate of Return

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Abstract

One of the most important factors to consider in building a new manufacturing system within a new plant is finding an effective layout. Laying out a plant involves deciding where to locate all the machines, work stations, and other equipment in the manufacturing operation. Many processes and activities like material handling, loading, unloading, and flow-through operation could be affected by machine layout. Small changes in the position of a machine in a plant can affect the efficiency and the cost of overall manufacturing operations. Simulation optimization studies were performed to examine different kinds of CNCs, equipment, configurations, and set up by using Arena software to simulate four different scenarios.

Results showed that scenario 4 (automated system with single spindle machines and cooling tunnel) was the optimal configuration. In addition, significant improvement on profit, rate of return, and overall system efficiency has been achieved as follows: increase in net profit from $18.3M to $20.9 M per year (14.2%), increase in rate of return from 20% to 33% per year (65 %) and reduce operation expenses and total cost

Keywords
Simulation, Layout, FMS, Engine Blocks, Profitability and Rate of Return

1. Introduction

In contrast, inappropriate layout can lead to process bottleneck, inflexibility, and complexity. Changes in machine layout could be very costly or impossible, so it is best to get it perfect in the design phase. In designing configurations of systems, the machine layouts are considered critical design issues Koren and Shpitalni. (2011), Johansson (2011), Erdin et al.(2010), and Ferreira et al. (2013) investigated the performance of machine layout and how to automate the process by focusing on manufacturing limits, system architecture and machine layout needed to make systems flexible. Simulations were used to evaluate different scenarios and to select the appropriate one. Ficko et al. (2015) proposed a study to remove constraints regarding the design of layout of flexible manufacturing system. The proposed system is composed of a creative subsystem which can use different optimization methods for evaluating layout of machines. Al Geddawy et al. (2010) developed a new model to optimize the layout of delayed differentiation assembly lines for mixed products. The result showed that the quantities required for multi products are produced on the same line with maximizing overall system utilization.

With global economic variables and competition, manufacturers encounter strategic challenges of accurate pricing and rising costs. Products become more complex with frequent aspect developments while target price-points fall progressively. Furthermore, global demand continuously shifts to dramatically growing emerging markets where competition totally depends on price. Against this backdrop, OEMs should continue to create and bring new products to the market cost-effectively and within compressed time frames. To identify these challenges, OEMs are trying to reduce the cost of their products. To do so, companies must assess their product realization value chain from a viewpoint of total cost optimization. Also, many companies adopt few initiatives that concentrate on opportunities in product and process development to optimize their product costs. Giaed et al. (2010) and Boysen et al. (2009) mentioned that in a mass-customization environment, both suppliers and their customers can benefit from knowing the sequence in advance in order to reduce costs. Tolio et al. (2013) and Carlo et al. (2012) proposed that the configuration and reconfiguration approaches were applied to minimize the equipment cost and evaluate the manufacturing system. Results showed that the proposed study reduced the total costs by an average of 25%. Sancak et al. (2011), Goren et al. (2010), Gyulai at al.(2015), and Mak at al.(2014) explored the impact of lot size and its interaction with operator competence on manufacturing system performance and minimizing costs using simulation techniques. They split the customer order into lots of different sizes to avoid late production planning and to minimize the costs. Falcone et al. (2013) proposed a discrete optimization model to address the problem of flexible machines in a manufacturing system in order to minimize handling costs associated with transferring parts between machines. Different scenarios were proposed to provide the best solution to solve the problems.

1.1Case Study

General Motors has decided to keep ahead of the competition and to invest a great amount of money to build a new, flexible manufacturing system for a new plant to produce 1,200 engine blocks per day. To achieve that volume, the company has to spend a lot of money on CNCs, automation, and other equipment. The upper management of the company had serious concern about the profitability and rate of return of the system because total cost of production is expected to be very high as a result of the high number of working hours, daily expenses, large footprint, work force, and labor wages. In this paper we will focus on economic analysis. Also, we must come up with new scenario to achieve more jobs per day, profit, rate of return and exceed the company target with less cost.

2.0 Methodology

Simulation optimization studies have been used to evaluate four different scenarios of new engine block manufacturing systems. Also cost and rate of return analysis were used to examine system's profitability and rate of return. Figure 1 shows the flow chart of simulation optimization study.

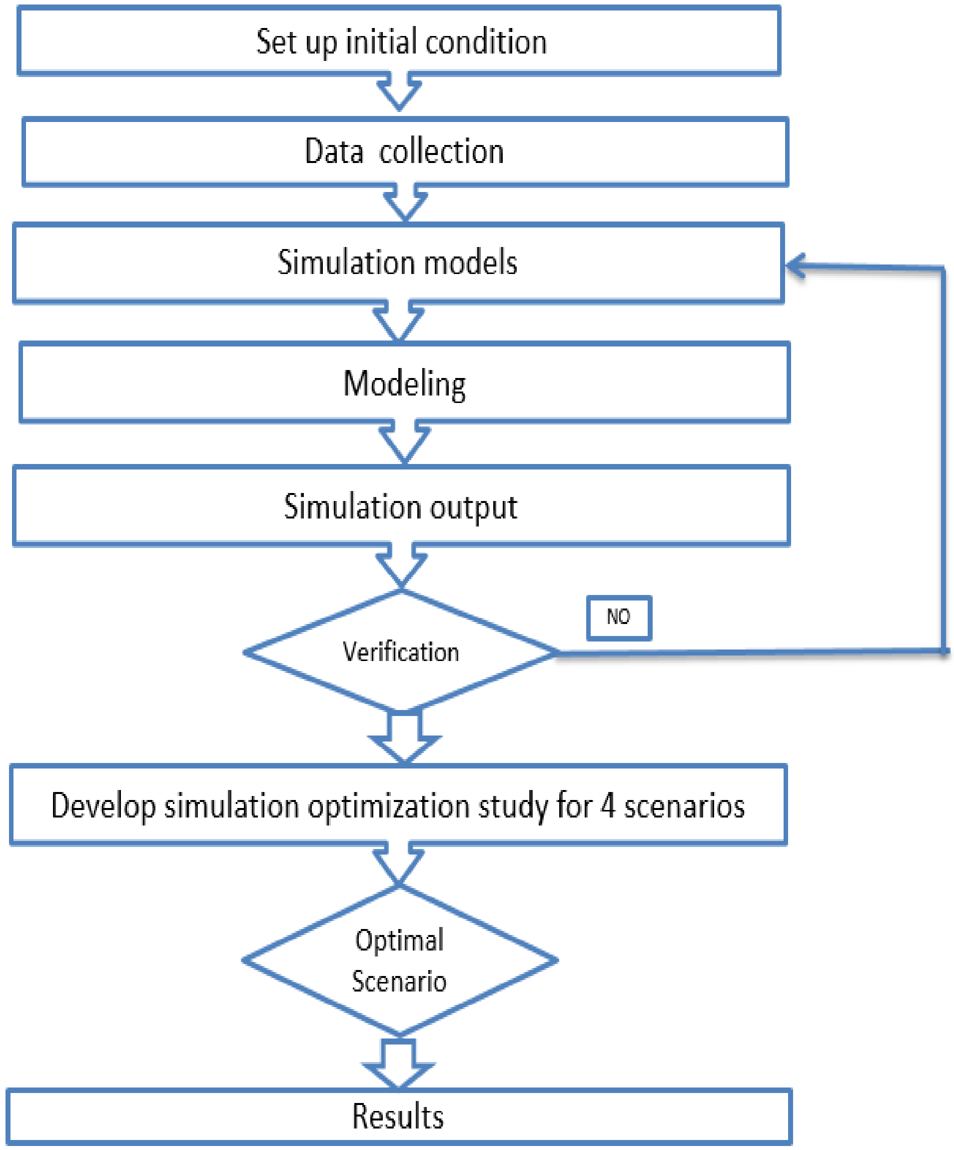

Figure 1. Flow chart of simulation optimization study

2.1 Simulation Models

Depending on the initial conditions, assumptions, system requirement and all the associated processes, four different configurations of machine layouts were proposed in Figures 2, 3, 4, and 5. Table 1 provides more details about the differences among all four scenarios.

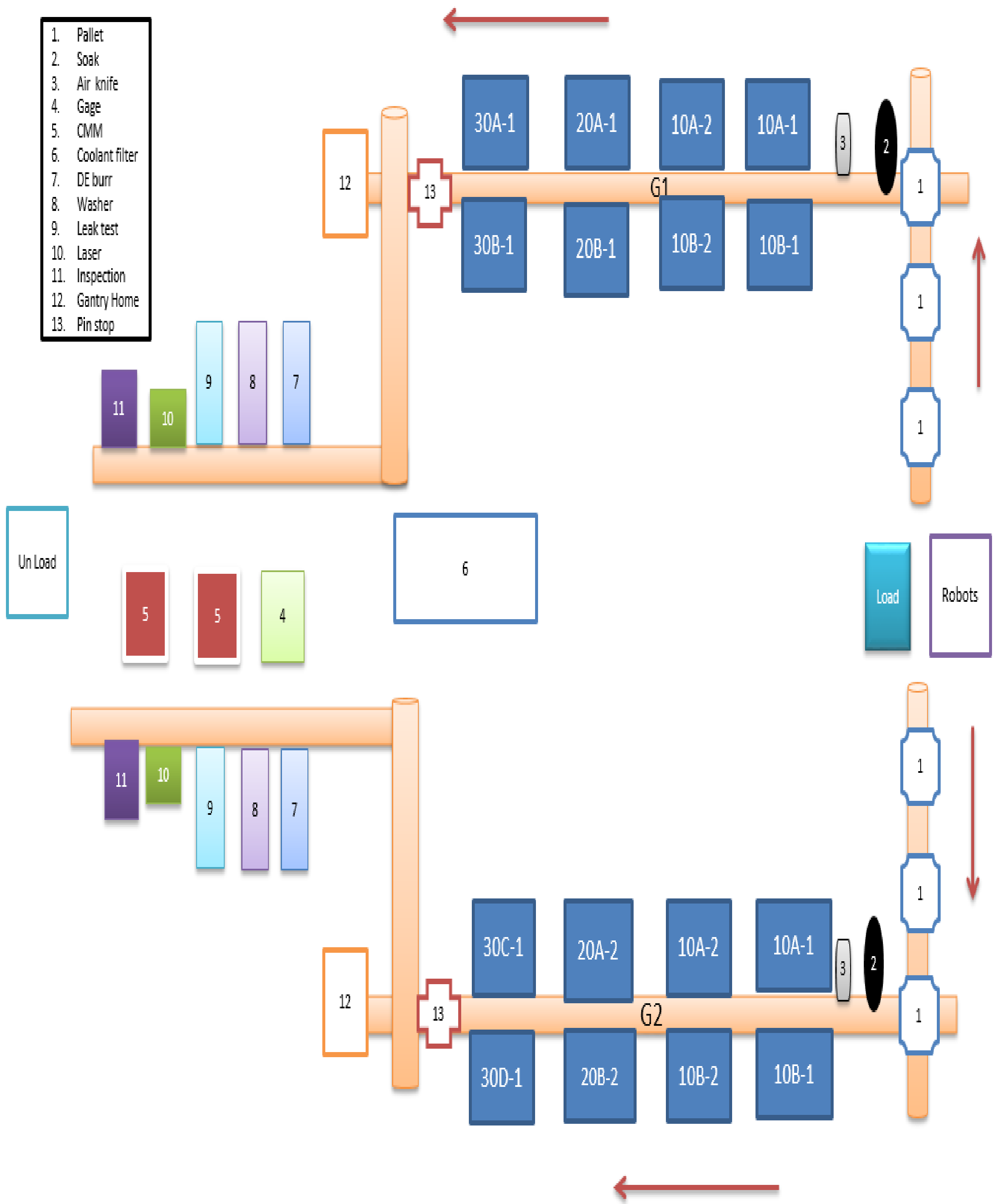

Figure 2. Machine layout: Scenario 1

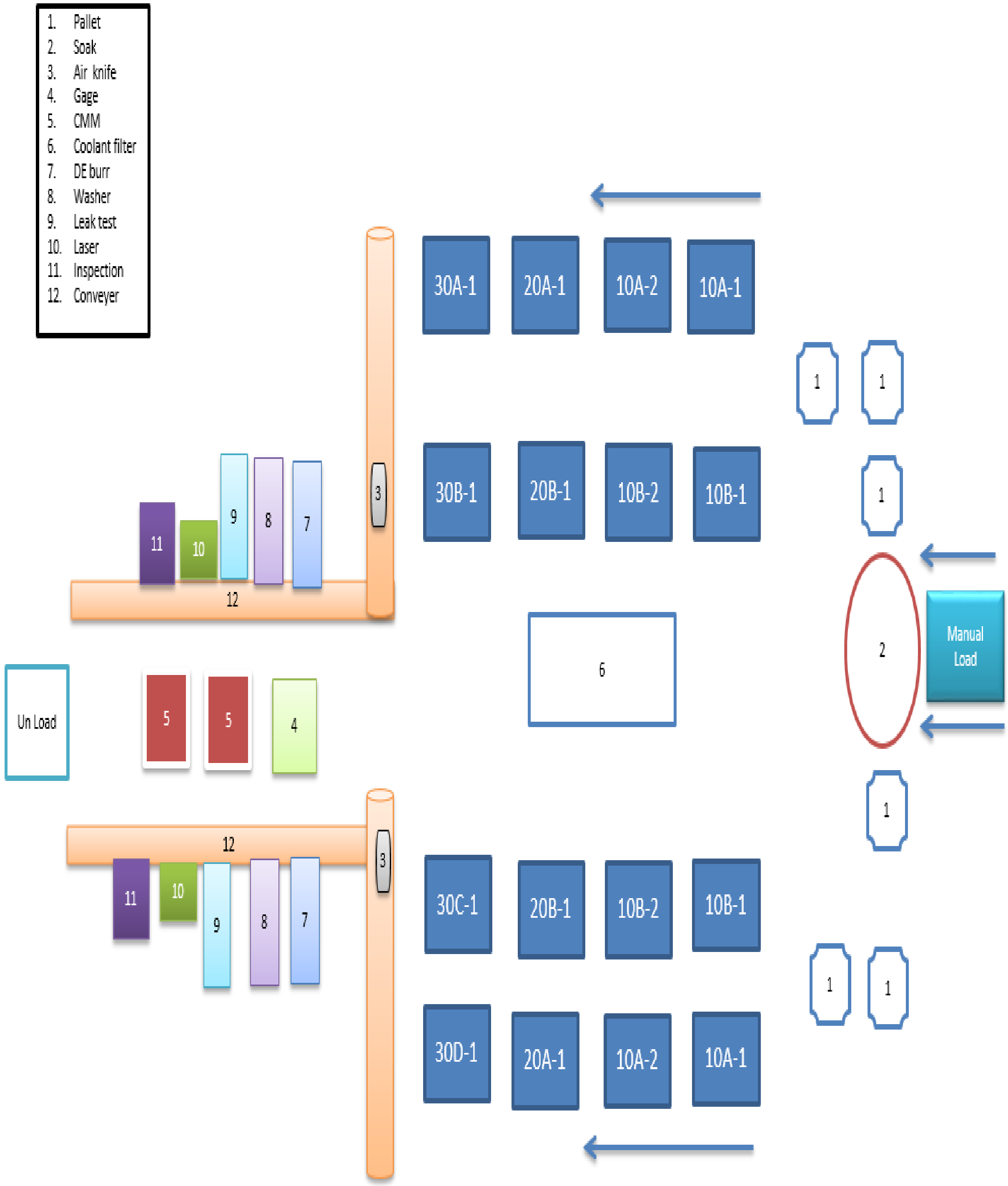

Figure 3. Machine layout: Scenario 2

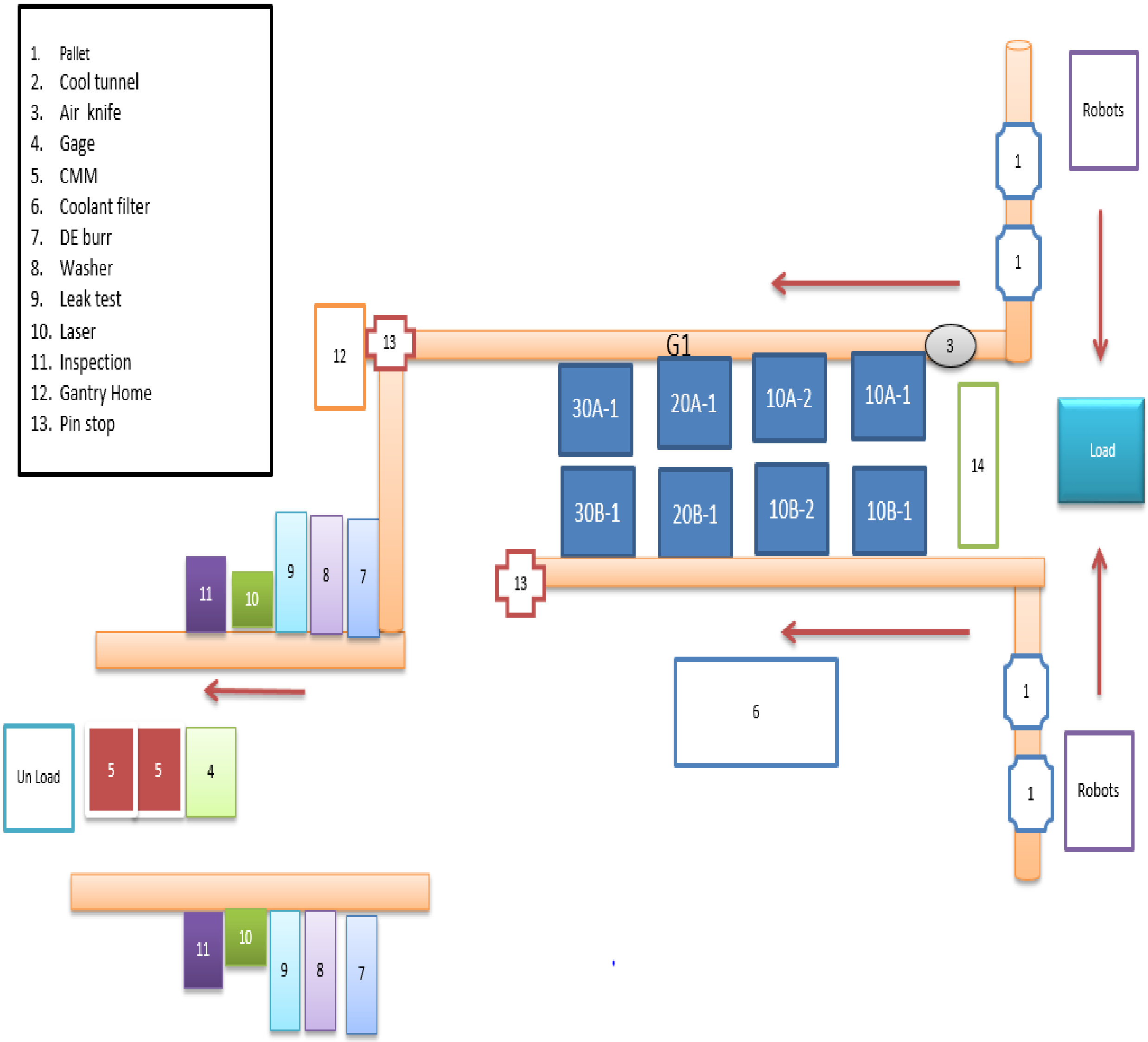

Figure 4. Machine layout: Scenario 3

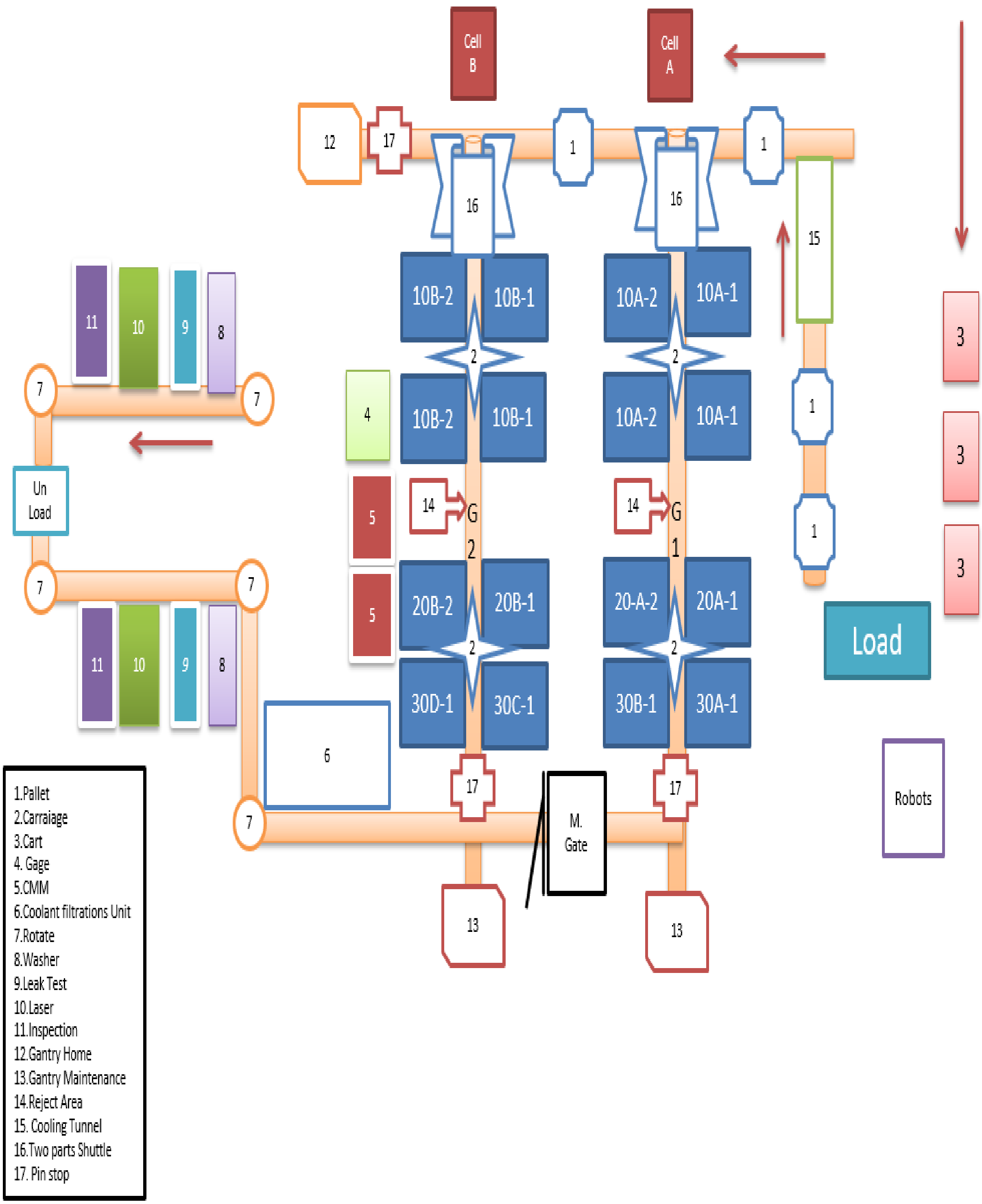

Figure 5. Machine layout: Scenario 4

Table 1. Scenario components

Equipment	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Robots	6	0	6	6
Gantries /Cartesian	2	0	0	2
Gantries /Robotic	0	0	2	0
Manual transporter	0	2	0	0
Soak	1	1	0	0
Cooling tunnel	0	0	1	1
CNCs dual	0	0	8	0
CNCs single	16	16	0	16
De burr	2	2	2	2
Washer	2	2	2	2
Leak test	2	2	2	2
Laser	2	2	2	2
Inspection station	2	2	2	2
CMMs station	2	2	2	2
Gage bench	2	2	2	2
Filtration station	2	2	2	2
Conveyers	2	2	2	2
Unloading station	1	1	1	1
Accessories	Same	Same	Same	Same

Table 2. Profitability analysis

	Equipment cost ($ Million)	Construction & installation cost ($ Million)	Yearly operation cost ($ Million)	# JPD	$ per unit	Yearly sales ($ Million)	Net profit ($ Million)
Scenario 1	25.9	8.3	8.8	1293	191	61.75	18.75
Scenario 2	24.15	8.3	9.7	1285	191	61.36	19.21
Scenario 3	23.15	8.3	10.35	1287	191	61.45	19.65
Scenario 4	24.9	8.3	8.8	1301	191	62.12	20.12

3. Profitability Analysis

After running simulation optimization studies for all scenarios. Table 2 shows jobs per day, equipment cost and cost of operation. Figure 6 shows profitability analysis for all scenarios depending on information in table 2. Equation 3 shows profit calculation.

Profit = total sale - total cost ………………………………………………………. (3)

When

Total sale = # JPD * # of working days * unit price per part…………………………. (4)

Total cost = cost of (equipment + construction and installation + yearly operation)...... (5)

Also, some of this information has been delivered by GM. Results show that Scenario 4 is the highest achievement in sales and profitability.

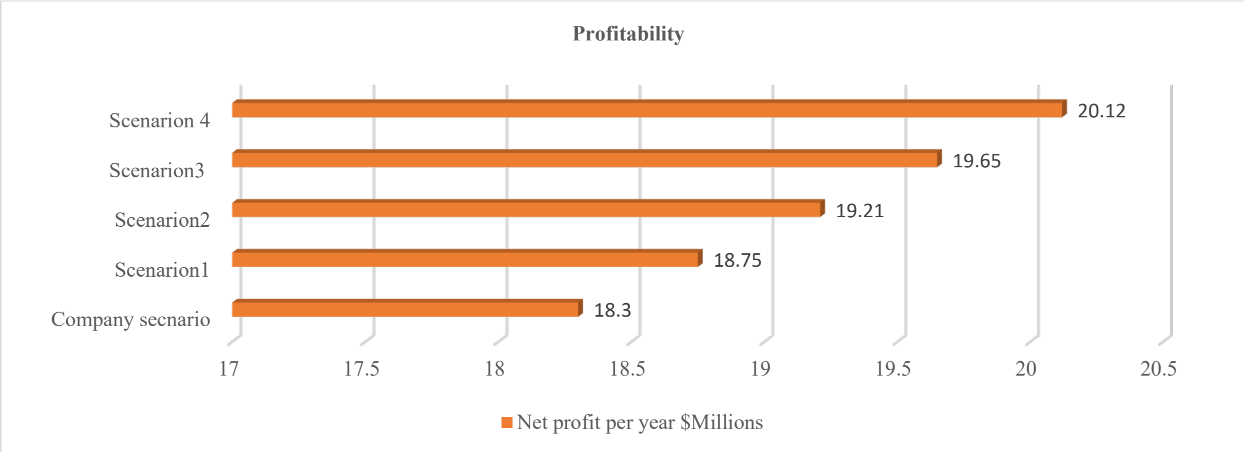

Figure 6. Profitability analysis

3.1 Rate of Return Analysis

A rate of return is the net gain or loss of an investment over a specified time period, expressed as a percentage of the investment's initial cost. When calculating the rate of return, you are determining the percentage change from the beginning of the period until the end. Rate of return is the most frequently used measure in manufacturing world. One of its major advantages is that it's a single figure of merit that is readily understood. The metric of rate of return can be used on a variety of assets, from stocks to the investment in manufacturing systems. The effects of inflation are not taken into consideration in the simple rate of return calculation but are in the real rate of return calculation.

Net present worth = net present benefits – net present cost………………………………….. (6)

or NPW = NPB - NPC

To calculate the rate of return, set NPW = 0

NPB = NPC [148] ….. (7)

Equation 4 shows total sales which equal to NPW. Also, Equation 5 shows total cost, which is equal to NPC. Table 10 helps to calculate the rate of return of all scenarios as follows:

For Scenario1

(25.9M + 8.3M) + 8.8M(P/A, i, 15) = 18.75M (P/A, i, 15)

34.2M + 8.8(P/A, i, 15) = 18.75M (P/A, i, 15)

34.2M = 18.75M (P/A, i, 15) – 8.8 (P/A, i, 15)

34.2M = 9.95 (P/A, i, 15)

(P/A, i, 15) = 34.2/9.95 = 3.43

From the compound interest table matching the present worth factor find P given A, (P/A), for a 15-year investment: Rate of return = 25%

For Scenario2

(24.15M + 8.3M) + 9.7M(P/A, i, 15) = 19.21M (P/A, i, 15)

32.45M + 9.7M(P/A, i, 15) = 19.21M (P/A, i, 15)

32.45M = 19.21M (P/A, i, 15) – 9.7M (P/A, i, 15)

32.45M = 9.51M (P/A, i, 15)

(P/A, i, 15) = 32.45/9.51 = 3.41

From the compound interest table matching the present worth factor find P given A, (P/A), for a 15-year investment : Rate of return = 27%

For Scenario 3

(23.15M + 8.3M)+10.35M (P/A, i, 15) = 19.65M (P/A, i, 15)

31.45M + 10.35M (P/A, i, 15) = 19.65M (P/A, i, 15)

31.45M = 19.65M (P/A, i, 15) – 10.35M (P/A, i, 15)

31.45M = 9.3M (P/A, i, 15)

(P/A, i, 15) = 31.45/9.3

(P/A, i, 15) = 3.38

From the compound interest table matching the present worth factor find P given A, (P/A), for a 15-year investment: Rate of return = 29%

For Scenario 4

(24.9M + 8.3M) + 8.8M(P/A, i, 15) = 20.12M (P/A, i, 15)

33.2 M + 8.8M(P/A, i, 15) = 21.2M (P/A, i, 15)

33.2M = 20.12M (P/A, i, 15) – 8.8M (P/A, i, 15)

33.2 M = 11.32 (P/A, i, 15)

(P/A, i, 15) = 33.2/11.32

(P/A, i, 15) = 2.93

From the compound interest table matching the present worth factor find P given A, (P/A), for a 15-year investment : Rate of return = 33 %. Figure 7 show that Scenario 4 is achieving the highest level of rate of return.

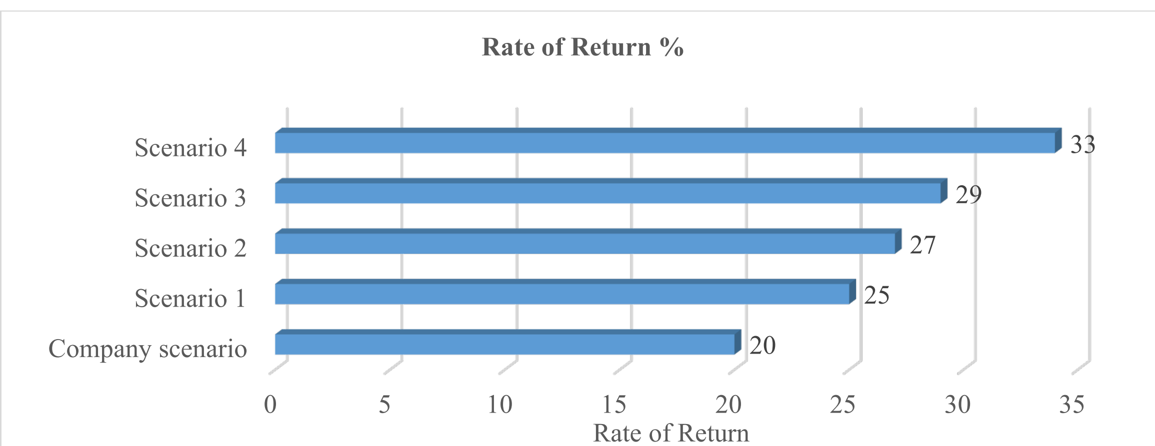

Figure 7. Rate of return analysis

4.0 Results

After running simulation and cost optimization studies, choosing an optimal scenario goes as follows:
1. Will not go with Scenario 1,2 and 3 (even though they achieved above system target) for the following reasons:
    - Scenarios 1, 2and 3 did not achieve the highest increase in JPD, net profit and rate of return compared to Scenario 4.
    - There are significant environmental issues that will be associated with the water when using soak for cooling process. Also, systems will be less efficient with water cooling due to more details, maintenance, and downtime, therefor Scenarios 1 and 2 are not recommended.
    - For scenario 3, there are significant quality issues to be expected with the machining process due to misalignment and tolerance limitations. Also, Scenario 3 is less flexible than others due to using 8 dual spindle CNCs instead of 16 single-spindle CNCs. If one machine breaks down (operation 10), the system will lose 50% efficiency.
2. Scenario 4 is the optimal scenario for the following reasons:
    - Scenario 4 achieved the highest increase in JPD and net profit. Also, system will be more efficient with cooling tunnel due to fewer details, maintenance, downtime and less environmental issues due to using cooling tunnel. In addition, Flexible system due to using single-spindle CNCs, as well as for long-term investment, scenario 4 will provide the highest rate of return. Table 3 and figure 8 show overall optimization studies.

Table 3**.** Optimization analysis

	# JPD	**Net profit ($ Million)**	**Rate of return %**
Company Scenario	1200	18.3	20
Scenario 1	1293	18.75	25
Scenario 2	1285	19.21	27
Scenario 3	1287	19.65	29
Scenario 4	1301	20.12	33

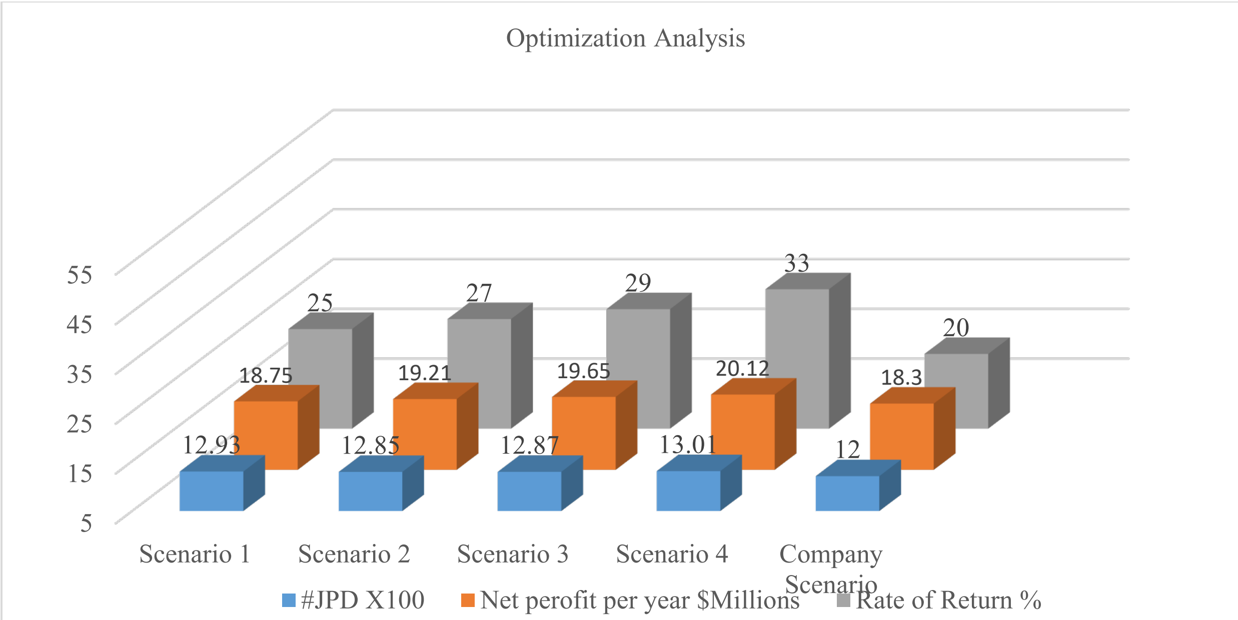

Figure 8**.** Optimization analysis

4.1 Summary

Arena software has been used to simulate four different scenarios. Also cost and rate of return analysis were used to examine system's profitability and rate of return. Results showed that Scenario 4 was the optimal process. In addition, significant improvement on throughput, profit, rate of return, and overall system efficiency have been achieved. Scenario 4(automated system, single spindle machines, cooling tunnel and robotic gantry) achieved the following:

- Increase in net throughput from 1200 to 1317 units per day (9.75%)
- Increase in net profit from $18.3M to $20.9M per year (14.2%)
- Increase in rate of return from 20 % to 33% per year (65%)
- Reduce safety issues and environmental issues
- Reduce operation expenses and total cost

Also inflation rate has not been considered in this study due to high rate of return achievement.

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Biographies

Khaleel Al ithawi, Ph.D. is a senior manufacturing engineer in Troy Design and Manufacturing. He received his Ph.D. degree in engineering manufacturing systems from Lawrence Technological University. His research has been in the areas of simulation optimization studies, design of experiment, modeling, process, development and manufacturing. He worked at former Iraqi Army -air force as aeronautical engineer and, later, was instructor in military engineering collage, He taught heat transfer, thermodynamics and engineering analysis. He currently working on prototyping, modeling and manufacturing of new models within automotive industry-North America.

Kingman Yee, Ph.D. is an associate professor and director of the M.S. automotive engineering program in the A. Leon Linton Department of Mechanical, Industrial and Robotics Engineering at Lawrence Technological University. He received his Ph.D. degree in chemical/electrochemical engineering from Wayne State University. His research has been in the areas of electrochemical engineering, corrosion, amorphous semiconductors and manufacturing. He worked at General Motors Research Laboratories and, later, was a consultant in Advance Manufacturing Engineering at Chrysler LLC (low-voltage electric clamps, multi-stage modular vacuum cartridges/generators, and resistance spot welding.) He currently teaches courses in engineering materials, heat transfer, engineering economics and senior capstone projects.

Dr. Abro was born and grew up in Baghdad; his family migrated to the US in the late sixties.
Sabah is an internationally-educated person with a bachelor degree from Baghdad University, a master's degree from the United Nations institute in the Middle East, a Master's degree from Britain and a Ph.D. from Belgium. Dr Abro is also certified Master Blackbelt in Six Sigma from Ann Arbor, USA firm.
His education helped him to learn four languages, Arabic, English, French and Chaldean.
Sabah's family is also international, his wife Ann and him are from Baghdad, their daughter Hadeel was born in Britain, their son Fadi in Belgium, their daughter-in-law Marsha in USA, Mark their son- in- law in Mosul, Iraq and their three grandchildren in Michigan.
Dr. Abro served in Universities in Iraq, Jordan and also as a visiting lecturer in Kuwait and Morocco. He assumed different positions such as faculty, regional consultant, chair of department and acting Dean.
In the USA he taught at WSU, UDM and OCC. He was the Math Program Director of Focus: HOPE where he worked with the curriculum committee of the Greenfield Coalition, an NSF sponsored group. This committee designed a complete paradigm in manufacturing engineering education. Courses were developed and delivered at Focus: HOPE by three university partners.
Sabah joined LTU as an adjunct faculty in 1997, then as a full-time faculty in 2000. He served two departments, Math & Computer Science and Engineering Technology.

As a full time, faculty at LTU, he teaches a variety of classes related to Quality, Probability, Engineering Economic Analysis, Engineering Project Management, advises students, works on curriculum improvement, course development, writes professional papers and presents in conferences. He is the Director of Master's program in Engineering Technology, advises and teaches courses for Doctorate students and is a member of several Doctorate Committees in the College of Engineering.
His services go beyond his department, where he serves in different Doctoral Committees in other Departments of the College of Engineering
Dr. Abro served as Director of the University Assessment Committee and the Vice Chair of the Engineering Faculty Council.
Winner of 2012 Faculty of the Year Award at Lawrence Technological University.
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His hobbies are many, but his addictions are to play racquet ball and watch movies, where he has special interest in classical western and action movies.

Dr.Ishtiaq Hussain Works in General Motors Powertrain division. Lead and executed and launched multiple metal cutting CNC machines lines at various sites for various Engine and Transmission components. Six sigma certified international professional, with 21 years of experience in engineering Project Management, Quality Management, and Process Engineering. Published several papers on Minimum Quantity Lubricant (MQL) topics. Expert in data analysis, metal cutting, and Leak test equipment. Adjunct faculty in Lawrence Tech. University Southfield MI.

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