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Design and Development of Mine Railcar Components

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Abstract In this paper, two of the vital mining railcar components have been designed. In this paper, a comparison has also made with current and proposed manufacturing process. Furthermore, Value stream mapping (VSM) has been analyzed through wagon and coupler manufacturing process and it has been shown that 15 % non-value adding time and 20 % labor can save though implementing the VSM methodology. Moreover, the proposed wagon body design has been proposed to save 30% unloading time. Additionally, proposed simplified coupler design can save 18% manufacturing cost.

Keywords: *SM, coupling, retention time, cos effective, efficiency, laborintensive*

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1. Introduction

Mining industry is struggling for improving productivity. A gondola is a railcar used for transporting bulk materials, such as gravel or coal, at approximately 100 tons per railcar. These loads create a total railcar weight that can exceed 286,000 pounds [1]. As railcar weights increase to improve capacity efficiency, new methods and devices can be implemented to increase railcar performance and service life.

The body of the railcar sits on two wheel and axle suspension assemblies called trucks. The body of the railcar contacts each truck at a center bowl and two side bearings [2]. The center bowl, which takes approximately 90% of the cargo load and railcar self-weight, is a cylindrical bowl that contacts the center plate on a flat surface [3]. A center pin runs through the middle of the center bowl/center plate assembly and alignments the truck and railcar body during maintenance. The side bearings, which may or may not be in constant contact over various loading conditions, prevent excessive rocking of the railcar [2].

Currently, the Association of American Railroads (AAR) requires center bowl liners or other lubricants that reduce friction and wear between the center bowl/center plate bearing surfaces [4]. Over time, plastic or metallic center bowl liners wear down and must be replaced. Replacement decreases productivity and adds maintenance costs. Research shows that liners fail when center bowl/center plate contact shifts from flat, evenly distributed contact to point or edge contact [3].

In this research, illustrates the current manufacturing process and newly proposed manufacturing process of the mine car components. Figure 1 left side shows open top wagon which is generally used for the transportation for moving ore and materials produced in the process of traditional mining. Mine carts are seldom used in modern operations, having largely been superseded in underground operations (Especially coal mines). On the other hand, This research also explain about the current manufacturing process and newly proposed manufacturing process of universal rail coupler in Figure 1 right side. It is universal coupling by the design made in Solid works and do the proper material selection for producing the coupler.

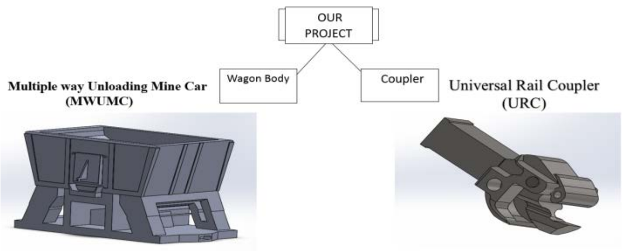

Figure 1. Multiple way unloading wagon body and coupler

2. Design

2.1. Design Concept

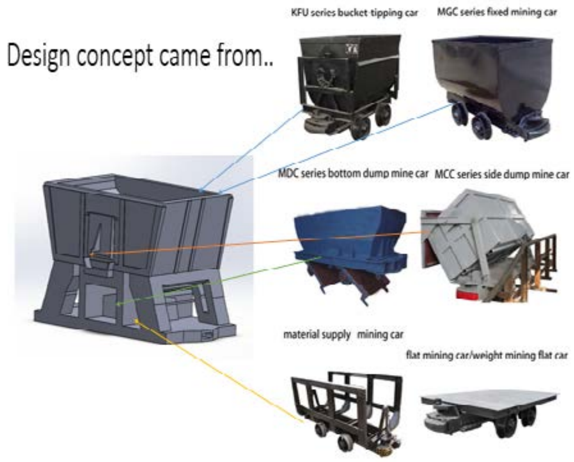

Figure 2. Design concept of multiple way unloading wagon body

By seeing the above Figure 2 present mine car are six types which are used for different purpose. One of the aims of the research to make one wagon which can do all the works by taking the unique components like bottom dump, side dump, material supply, fixed mining car. Furthermore, we will explain about material selection why we change the material, mechanism and cost of manufacturing the wagon.

2.1.1. Detail Explanation of the Wagon Body Proposed

- Under frame
- Centre Sill
- Body end
- End side
- Wheels
- Bogie
- Braking system.

2.1.2. Standard Feature of the 'MWUMC' WAGON

Table 1. Features of Wagon body

Sl.No	Features	Measurement
1	Length over head stock	3034mm
2	Length over couplers	3363mm
3	Length inside	2833mm
4	Width inside/Width Overall	1350/1450mm
5	Height inside/Height(max.) from RL	824/935 mm
6	Wheel dia. on tread (New/Worn)	350/650mm
7	Floor area (Sq.M)	13.56m2
8	Cubic Capacity (Cu.M)	1.54
9	No. of wagons per train	18
10	Coupler Buckeye coupler	
11	Bearing R.B.	
12	Maximum Speed (Loaded)	35kmph

2.1.3. Unloading of Material

The design of the steps in middle of the wagon is the key factor to unload the material. Once any door open the material drop immediately. In this paper, material unloading is other key factor and this material unloading can be done from three sides: 2 sideways and 1 bottom drop.

2.1.4. Sideways

The door has been designed in such a way that, once the pulley on the door touch the ramp where the material need to unload the door opens which is automatic no manual operation required which i**s key advantage of the project.** The door can open up to 30° then the material comes out and it closes automatic because of the weight of the door.

2.1.5. Bottom Drop

It required manual operation. It has a mechanism to open the door where the material drops from the bottom without disturbing the base. The design is made using Francis turbine (draft tube concept) and support head on the bolster which is designed to protect the bolster while unloading. The design of the unloading can be seen from Figure 3.

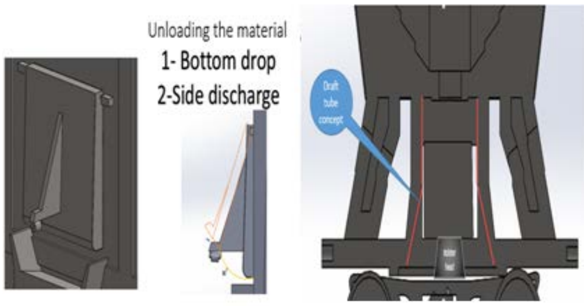

Figure 3. Unloading of material

2.2. Design of Coupler

A **coupling** (or a **coupler**) is a mechanism for connecting rolling stock in a cart. The design of the coupler is standard, and is almost as important as the track gauge, since flexibility and convenience are maximized if all rolling stock can be coupled together.

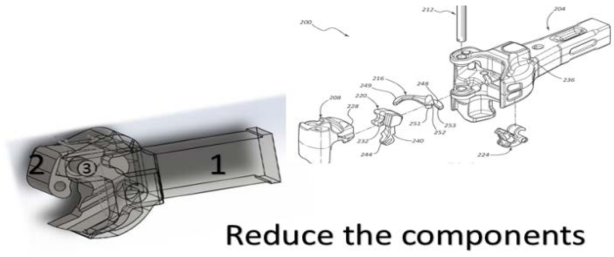

Figure 4. Railcar coupler components

The core aim of the coupler is to reduce the components and provide the coupler with better material than the existing coupler. By reducing the components, it will be more flexible and absorb shocks. Moreover, resulting process would be easy, reduce the cost depend on the material with this design and easy to operate when it would be manually connected.

3. Material Selection

Material selection is the vital phase of any manufacturing environment. There are some of the important factors are involved behind proper material selection e.g product longevity, cost sensitivity etc. So 3cr12 stainless steel would be more productive than 301 stainless steel in the case of wagon body sheets production. Because density of 3cr12 is less, resulting in, the total weight of the body would be lower which shown in Table 2. Additionally, this material also could be able to generate savings in maintenance, improve productivity and longer service life. Table 3 depicts the material selection for producing body frame where Al5005 alloy has been proposed in lieu of 301 stainless steel because it can be machined by conventional method, density is pretty less compared to iron, and welding can done by standard techniques i.e TIG or MIG. Table 4 discuss the material selection for base plate which is very important component of the wagon body that should bare total weight of the coal and so Al5042 has proposed for this parts as it should have higher tensile strength. In addition, Al 5042 has more life time compared to Al5050H32. 3cr12 stainless steel material has been proposed for the door of the wagon body which shown in table 5. This material has selected for the wagon body because it has good corrosion resistance and low friction.

Table 6 shows that 303 stainless steel has been selected for locking pin of coupler because it can resist corrosion from environments, acids, moisture and at high or low temperature. From Table 7 and Table 8 shows that 301 stainless steel has proposed because it has high strength and excellent corrosion resistance than any other materials. It can further be used at low temperature regions.

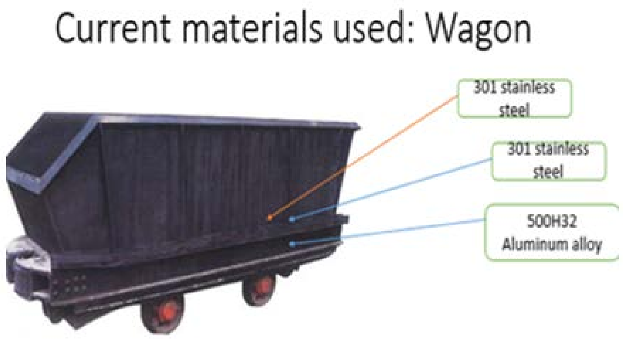

Figure 5. Current wagon body materials practice

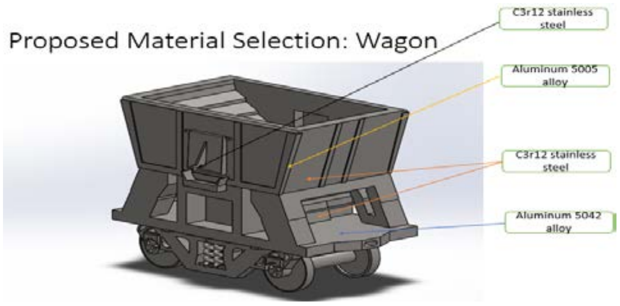

Figure 6. Proposed materials for wagon body

Table 2. Wagon body sheets material properties

301 Stainless Steel	3CR12 Stainless Steel
Current Material	Proposed Material
Density : 7880(kg/m^3	Density : 7740(kg/m^3
Elastic Modulus : 193 Gpa	Elastic Modulus : 200 Gpa
Yield Strength : 275 Mpa	Yield Strength : 280 Mpa
Hardness : 165	Hardness : 178
Ultimate TS: 758 Mpa	Ultimate TS: 650 Mpa

Table 3. Body frame material properties

301 Stainless Steel	Al 5005 Material
Current Material	Proposed Material
Density : 7880(kg/m^3	Density : 2700(kg/m^3
Elastic Modulus : 193 Gpa	Elastic Modulus : 68.9 Gpa
Yield Strength : 275 Mpa	Yield Strength : 131 Mpa
Hardness : 165	Hardness : 38
Ultimate TS: 758 Mpa	Ultimate TS: 200 Mpa

Table 4. Base plate material properties

Al5050H32	Al 5042 Material
Current Material	Proposed Material
Density : 2690(kg/m^3	Density : 2700(kg/m^3
Hardness : 46	Hardness : 96
Yield Strength : 145 Mpa	Yield Strength : 345 Mpa
Elastic Modulus : 68.9Gpa	Elastic Modulus : 70 Gpa
Ultimate TS: 172 Mpa	Ultimate TS: 360 Mpa

Table 5. Wagon body doors material properties

3cr12 Stainless Steel
Density : 7740(kg/m^3
Elastic Modulus : 200 Gpa
Yield Strength : 280 Mpa
Hardness : 178
Ultimate TS: 650 Mpa

Figure 7. Current railcar coupler materials practice

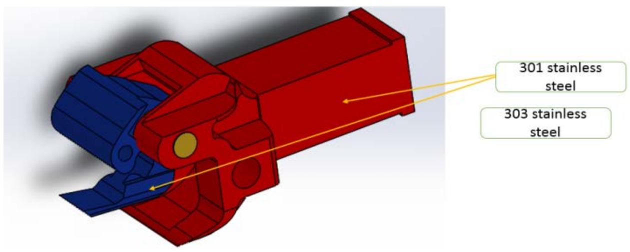

Figure 8. Proposed railcar coupler materials

Table 6. Coupler's locking pin material properties

Locking Pin	
Current Material (A396 ductile Iron)	Proposed Material(303 Stainless steel)
Density : 7113(kg/m^3	Density : 8027(kg/m^3
Hardness : 143	Hardness : 228
Yield Strength : 275 Mpa	Yield Strength : 415 Mpa
Elastic Modulus : 70Gpa	Elastic Modulus : 193 Gpa
Ultimate TS: 448 Mpa	Ultimate TS: 690 Mpa

Table 7. Coupler's knuckler material properties

Locking Pin	
Current Material (A396 ductile Iron)	Proposed Material(301 Stainless steel)
Density : 7113(kg/m3	Density : 7880(kg/m3
Hardness : 143	Hardness : 165
Yield Strength : 275 Mpa	Yield Strength : 275 Mpa
Elastic Modulus : 70Gpa	Elastic Modulus : 193 Gpa
Ultimate TS: 448 Mpa	Ultimate TS: 758 Mpa

Table 8. Coupler's jaw material properties

Jaw	
Current Material (A396 ductile Iron)	Proposed Material(301 Stainless steel)
Density : 7113(kg/m^3	Density : 7880(kg/m^3
Hardness : 143	Hardness : 165
Yield Strength : 275 Mpa	Yield Strength : 275 Mpa
Elastic Modulus : 70Gpa	Elastic Modulus : 193 Gpa
Ultimate TS: 448 Mpa	Ultimate TS: 758 Mpa

4. Process Flow Diagram

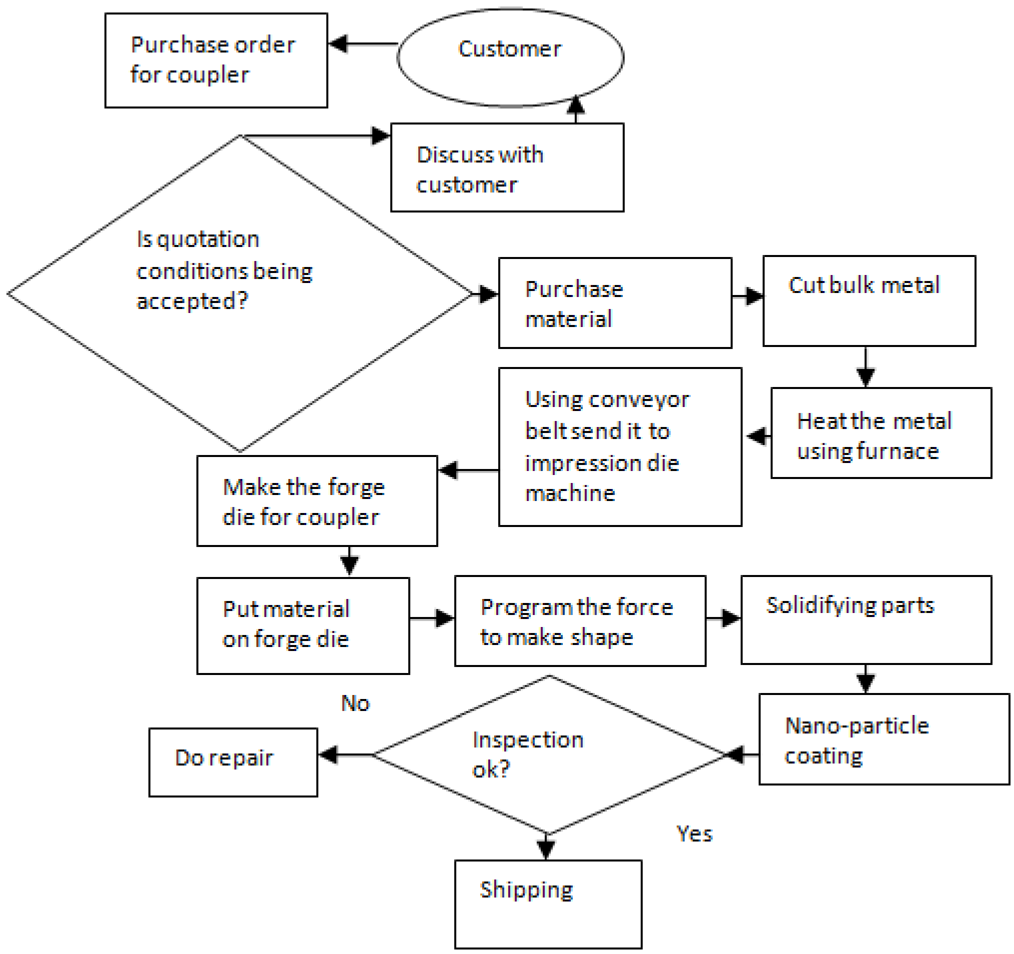

Figure 9. Current coupler manufacturing process flow

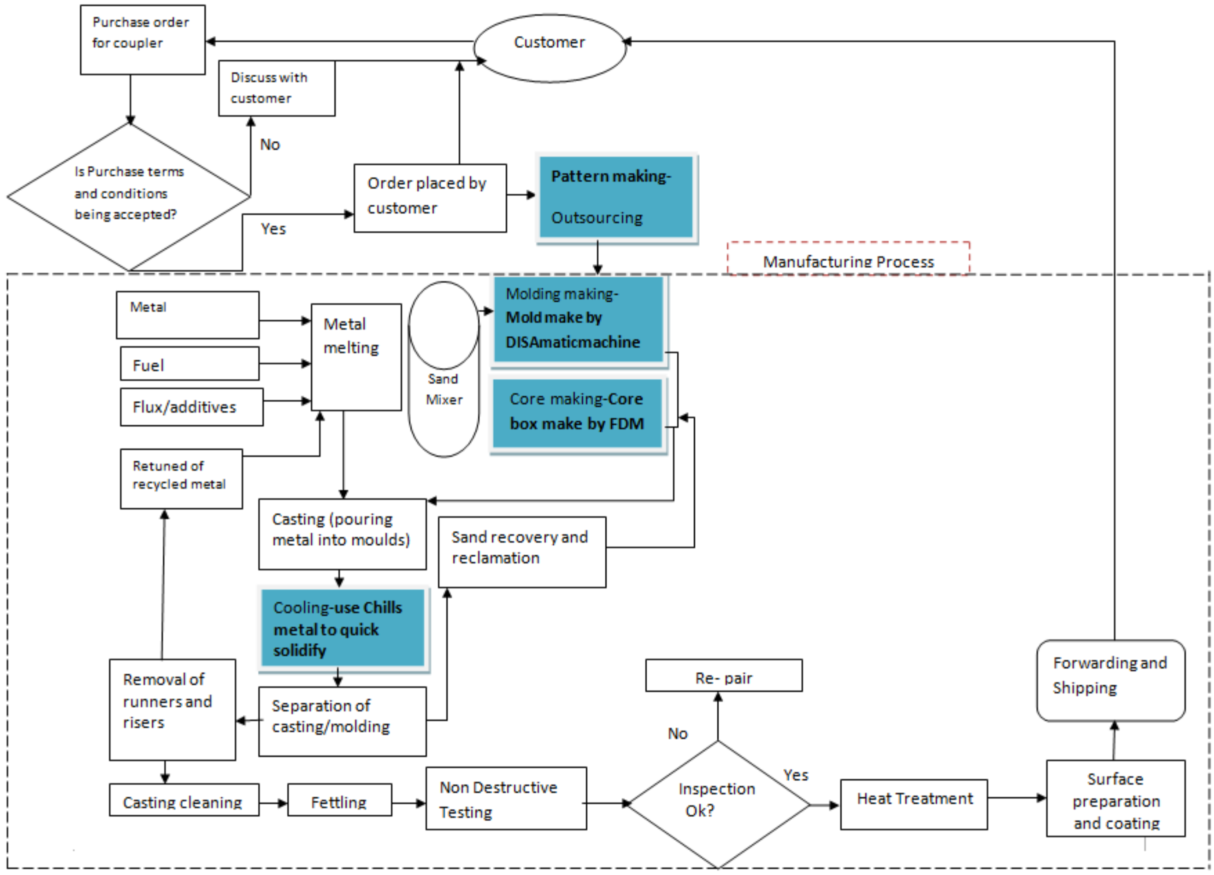

Figure 10. Proposed coupler manufacturing process

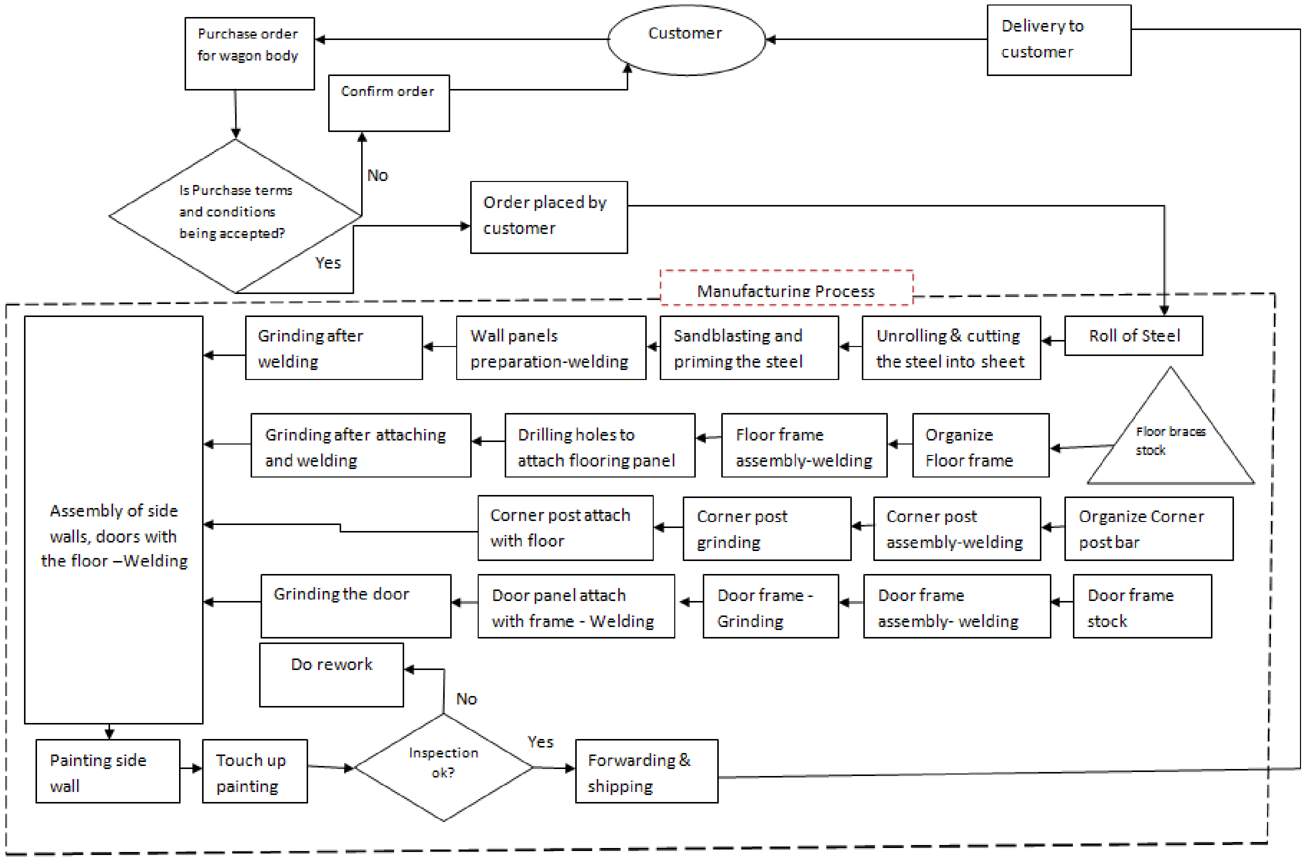

Figure 11. Current wagon body manufacturing process flow

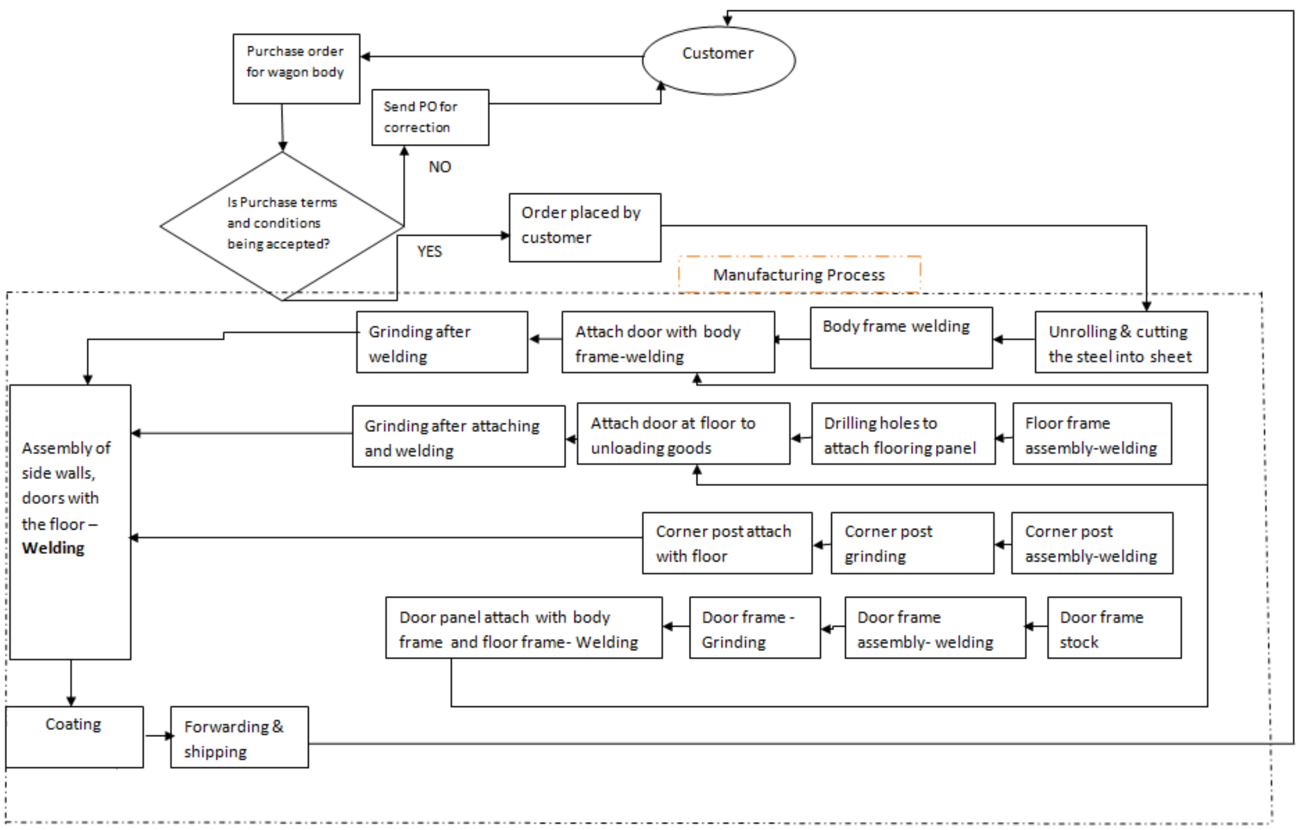

Figure 12. Proposed wagon body manufacturing process flow

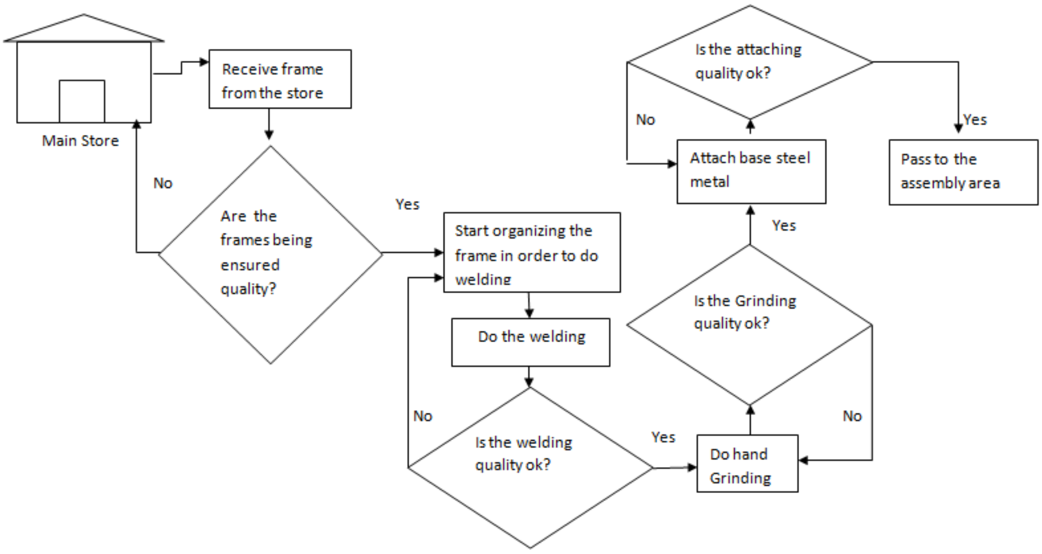

Figure 13. Framework of Poka Yoke

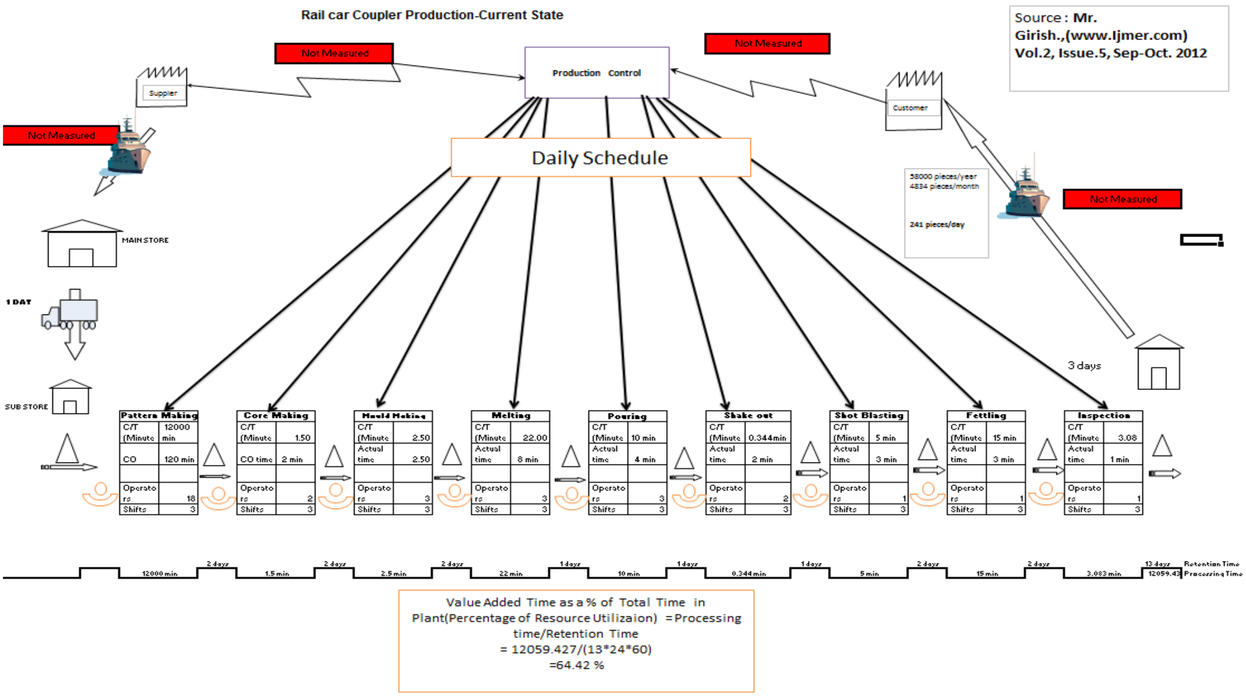

Figure 14. Current State of coupler's VSM

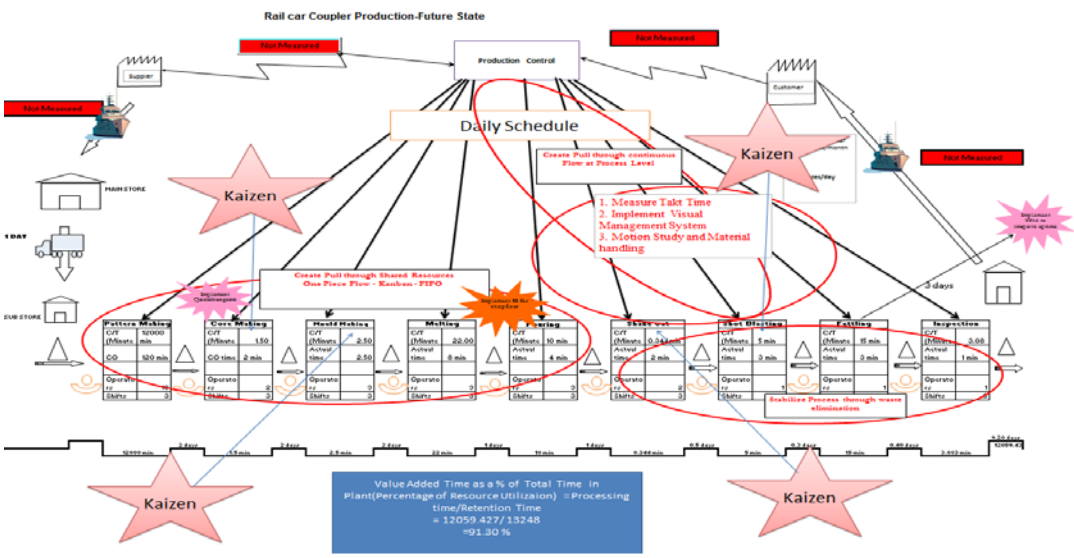

Figure 15. Future State of coupler's VSM

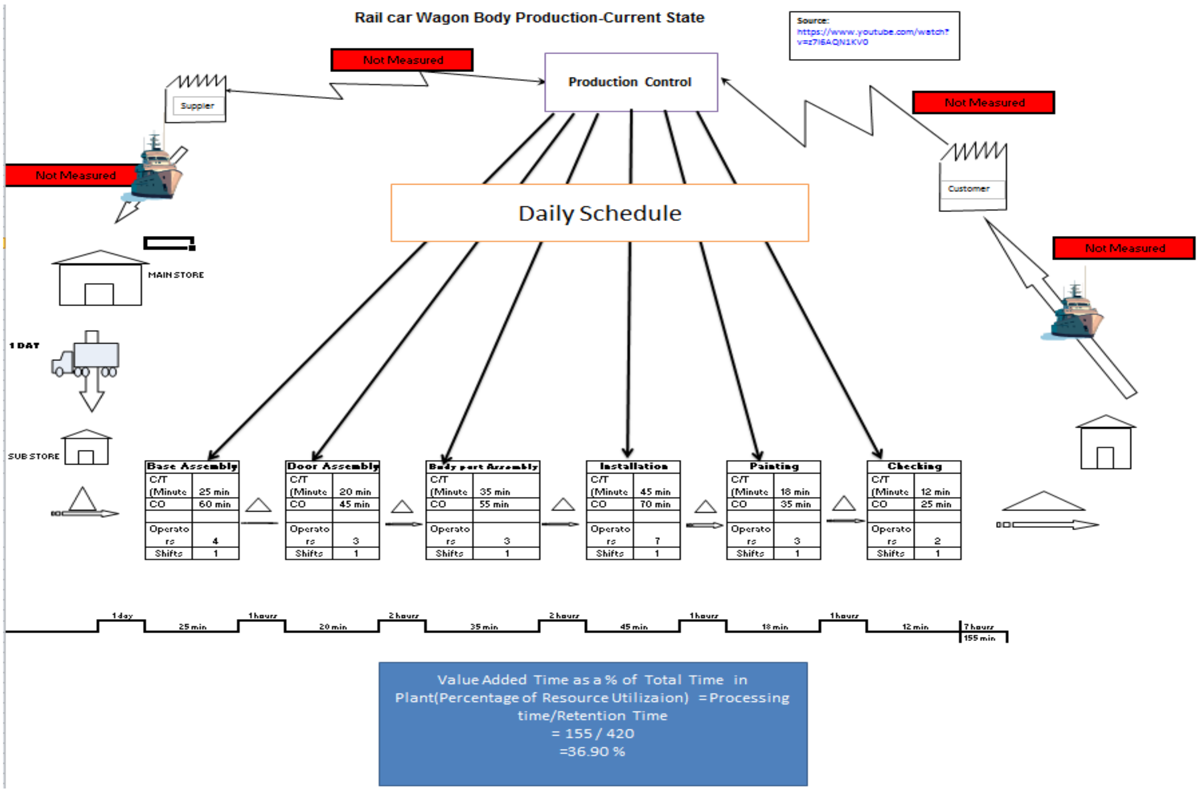

Figure 16. Current Value Stream Mapping for Wagon

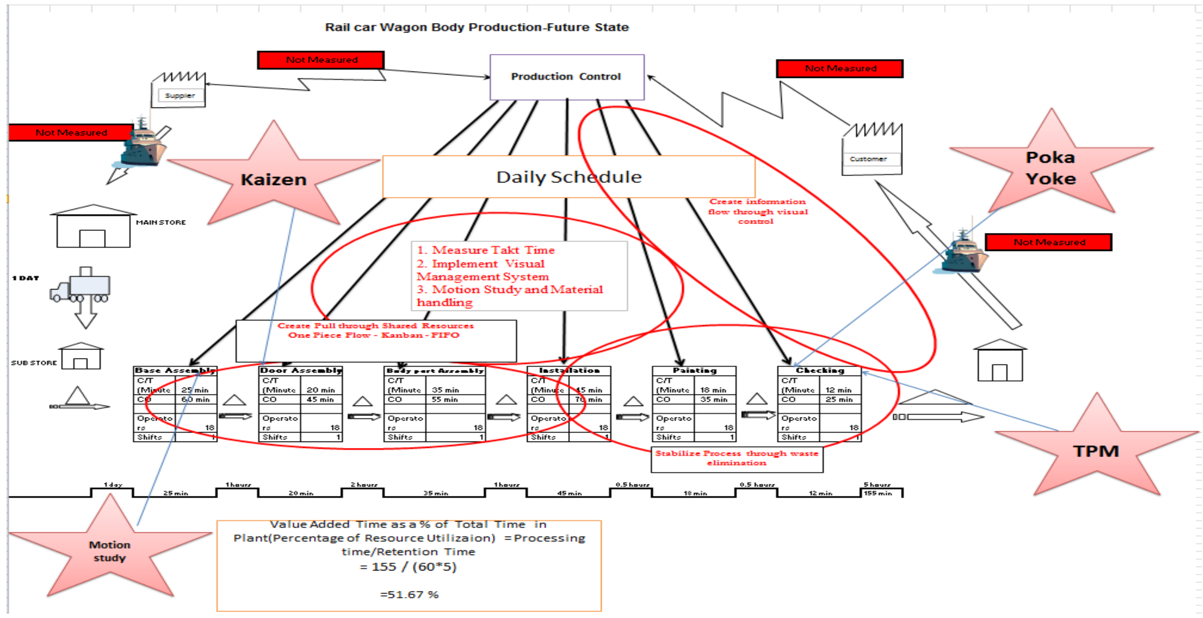

Figure 17. Future Value Stream Mapping for Wagon

Table 9. Cost –Benefit analysis for wagon body

Cost Benefit Analysis for wagon

	Present Process	Our Project	
Al,301 stainless steel			
Raw Material Cost/Ton	$3,800	$4,000	
Material required(700Kg)	2,500	3,000	3cr12 Stainless steel, 5005,5050h32 Al alloy
Transportation cost	100	100	Sheets,body frame,base and doors
Cost of Filler Metals	50	50	309 Filler material
Stamping Cost	50	50	
Painting Cost	50	50	
Drilling Cost	25	25	5356 Filler material
Grinding Cost	25	25	
Cost of rework	100	NA	
Repairs and Maintenance	100	100	
Labour Cost/Piece	100	75	
Cost Of Inspection	20	20	
Shipping cost	50	50	
Miscellaneous Cost	50	50	
Totals	$3,220	$3,595	

Table 10. Cost –Benefit analysis for coupler

Cost benefit analysis for coupler

	Present Process	Our Project	
ductile iron			
Raw Material Cost/Ton	$2,800	$3,500	
Material required (75kg)	210	265	301,303 Stainless steel
Cost Of Sand Casting	50	50	
Cost Of Shot Blasting	20	NA	
Cost Of Fettling	20	20	
Cost of cleaning the casting	5	5	
Cost of heat treatment	15	15	
Grinding Cost	15	15	
Inspecting cost	10	5	
Repairs and Maintenance	10	10	
Labour Cost/Piece	10	10	
Miscellaneous Cost	10	10	
Totals	$375	$405	

4.1. Technologies to Improve Process Flow

4.1.1. Fused Deposition Moldering (FDM)

Fused Deposition Modeling (FDM) and PolyJet are two of the most advanced and effective additive manufacturing (AM) or 3D printing technologies available. They span the range from budget-friendly, desktop modeling devices to large-format, factory-floor equipment that draw from the capital expenditure budget, and can produce a range of output from precise, finely detailed models to durable production goods. While there is crossover in applications and advantages, these two technology platforms remaindistinct and bring different benefits. Understanding the differences is the baseline for selecting the right technology for your application, demands and constraints [5].

4.1.2. Disamatic Modeling

Currently, all Metal Technologies foundries utilize Disamatic Molding Machines to produce molds for our castings. Disamatics offer a highly efficient means of rapidly and automatically creating a string of flaskless molds. These molds are built for vertical casting and are created in a vertical molding environment. For an explanation of the process, read through the text below and click on the thumbnail images to see illustrations [6].

4.1.3. Rate of Solidification Time

Solidification of casting in permanent (metallic) mold is much faster than in sand mold due to its high thermal conductivity. The rate of heat transfer is controlled at the interface between the solidifying metal and the metallic mould where air gap quickly develops [7]. This is especially important in permanent mould casting where the heat transfer between the casting and the mould are primarily controlled by conditions at the mould-metal interface. At the metal-mould interface the casting tends to shrink as it solidifies, creating areas where gaps form between the casting and the mould surface [8]. Solidification involves extraction of heat from the molten metal thereby transforming it to solid state at the solid-liquid interface. The rate of solidification is determined mainly by rate of heat extraction through conduction and convection and can be represented using cooling curves [9]. Permanent mould casting is the casting of metals by continually using a reuseablemould, thus making casting time much shorter than in temporary sand casting. Permanent mould casting can be gravity die casting; centrifugal casting; and die casting [10]. In this research, chiller metal have been proposed to optimize solidification time which might expedite the whole casting process.

5. Results and Discussions

Manufacturing organization now is struggling for improving productivity. They look for cost effective method to produce and sell the product since the market is now highly competitive. The manufacturing of railcar wagon body is the labor intensive process. Though manufacturer launch automation in order to make body part in some of the process however there are still a plenty of opportunity to reduce the labor from that kind of manufacturing industry. Today, customer is not only looking for on time delivery but also they are emphasizing more on right first time. There are some manufacturing engineering tools and techniques which might mitigate the cost and improve the quality of the wagon body while manufacturing. In order to do faster production, designing the railcar components is the preliminary step. In Figure 1 has shown wagon body and coupler design. The concept of design has come from six different existing wagon bodies which portrayed in Figure 2. The core idea of design is to do unloading of mine coal faster than the existing wagon body does. To do that, there are three doors has inserted at the proposed design as if coal can be unloading through these three doors easily and quickly. There are two doors on the side wall and one door on the bottom of the wagon body. On the other hand, coupler has been designed by optimizing six components into three components by keeping the same functions of the coupler shown in Figure 4.

In **Traditional** Coupler manufacturing process, forging process has been utilized to manufacture a coupler which has shown in Figure 9. However this process is time consuming, and expensive. Customer looking for faster delivery with least cost. So Sand casting process would be more cheaper manufacturing process. Though sand casting is the antique manufacturing process, this processing is labor intensive too. There are still a lot of opportunities to make the sand casting process efficient. Currently, Sand casting patterns are commonly produced by using computer numerical control (CNC) machining, but problems like incorrect shrink compensation and design flaws can occur which in turn require the pattern be reworked – creating additional costs and lead time that manufacturers cannot afford to outlay while under increasing pressure to improve time, cost and production efficiencies. There are some suggestions for making casting process expediting has shown in Figure 10 which also described below. The suggestion for making pattern by using FDM technology. FDM technology can implement in order to make the pattern with the use of 3D printing which can save cost in labor, time and expedite the whole manufacturing process. FDM technology can not only reduce the pattern making time and cost but also there are some of the other development can be brought in the current casting process. FDM Technology can also be used for core box production. The molding is the most time consuming process in the coupler manufacturing by using the casting technology. So the extensive level of time and labor can be saved by using DISAMATIC sand molding machine which the has several advantages comparing to conventional molding processes. It does not use flasks, which avoids a need of their transporting, storing and maintaining. It is fully automatic and requires only one monitoring operator, which reduces labor costs. Molding sand consumption can be minimized due to variable mold thickness that can be adjusted to the necessary minimum. The efficiency of the sand casting process while manufacturing railcar coupler can be improved by optimal designing of Riser. Risers are generally used for putting off of shrinkage defects. However, they decrease the usage rate of metal and extend the cooling time of castings after solidification as well. Therefore, proper riser size needs to be designed to satisfy feeding with the smallest volume.

The coupling manufacturing through the sand casting process might be accelerating by doing optimal gating design too. The gating design and in gate position plays an important role in the quality and cost of a metal casting. Due to the lack of theoretical procedure to follow, the design process is normally carried out on a trial and error basis. The time saving at the time of cooling while manufacturing coupler is another vast time saving improvement. Using metals like chills is an object used to do rapid solidification. In this research, the suggestions for internal chills metal which can be melted. When the cavity is being formed, chill metal parts will melt and finally become the portion of the casting product and thus the chill must be the same material as the casting. The advantages of the internal chill can absorb both heat capacity and heat of fusion energy.

In Figure 11 discuss the current manufacturing flow of wagon body where non-value adding activities has been adopted. But there are four way wagon body manufacturing process has depicted in Figure 12. The side wall produces by welding process. But it does not need to do grinding after welding as the chemical treating process has been proposed which would be faster and smooth process. Similarly, chemical dipping proposed for each parts of wagon body manufacturing i.e base and support, body frame and coal unloading doors.

The cost benefit analysis for wagon body has been shown in table 9. The current wagon body manufacturing cost is $3200 but the proposed wagon body manufacturing cost would be approximately $3600 per body. This price is very competitive though many features have been added into wagon body. Table 10 shows the cost benefit analysis of the coupler. The current and proposed price almost same but the quality of the coupler would be higher than existing as well as coupler can be delivered to the customer very quickly since some manual process has been eliminated while manufacturing through sand casting process.

The total retention time or non-value adding time for coupler is 13 days and processing time is 12059.43 minutes from Figure 14. Calculated the resulting percentage of utilization or value added time as percentage which was 64.42 % for the current state in case of coupler while doing VSM analysis. This is meant that there are still approximately 35 % opportunities remaining for improving utilization that leads to improving efficiency of the company. But Figure 15 state that there are most important waste reduction tools and techniques have been proposed to implement while manufacturing coupler of railcar. From the current state, it was observed that unnecessary time taken in between the shakeout and shot blasting, fettling and shot blasting, shot blasting and checking. The unnecessary time from that operation could be reduce through introducing Pull production methodology instead of push production, FIFO method, Kaizen, Visual management system, motion study and right material handling techniques. The proposed improved has been shown in the future state and If the company would implement the above mentioned techniques, higher productivity can be achieved. The proposed calculated percentage of utilization or value added time 84 % which is competitive and serving in the manufacturing competitive environment.

The total retention time or non-value adding time for wagon body is 7 hours depicted at Figure 16 and processing time is 155 minutes. Calculated the resulting percentage of utilization or value added time as percentage which was 36.90 % for the current state in case of body part while doing VSM analysis. This is meant that there are still approximately 64 % opportunities remaining for improving utilization rate that leads to improve the efficiency of the company.

But in the future state which has shown in Figure 17 that there are most important waste reduction tools and techniques have been proposed to implement while manufacturing coupler of railcar. From the current state, it was observed that unnecessary time taken in between the base assembly, Installation, painting and checking. The unnecessary time from that operation could be reduce through introducing Pull production methodology instead of push production, Kaizen, Visual management system, motion study and right material handling techniques, Poka Yoke and TPM. The proposed improved has been shown in the future state improving and If the company implement the above mentioned techniques. The proposed calculated percentage of utilization or value added time as percentage which is53 %.

6. Conclusions

In this paper, a lot of new things have been adapted while developing design and process. Furthermore ,we have successfully compared the current process and proposed process then by using VSM techniques that canreduce labor and inspection time which made our process boost from the existing, machine used in this process are automated with high quality which improve the productivity. We made a continuous flow of material unloading which has eliminate dumping system. In this paper, moreover focus on design which made the expedition throughout the manufacturing process. Furthermore, In this research , a tremendous improvement has done by reducing labor from the manufacturing activities. Design of the railcar wheel mechanism as well as fabricating the wagon body and coupler as per design would be further recommendation for the future research.

Acknowledgement

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moreover for providing has with an opportunity to work and gain experience.

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