ENPM 692 - Manufacturing and Automation

Automating the Part Inspection Process in Automobile Manufacturing

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1. Abstract

The vehicle manufacturing industry has always been on the cusp of innovation and implementation of new ideas. Be it the first vehicles with internal combustion to the autonomously driven cars of today, they have always been the constant adopters of novel processes to help improve their manufacturing abilities. Being such important players in the industry, one must ask oneself, “Are they innovating at every process of their lifecycle?” To answer this question, we must look at all the processes involved in the manufacture of vehicles and then one area clearly stands out where vehicle manufacturers have had their hands tied. In the car body manufacturing process, once each of the parts is processed after forming and press stamping process, there is a human in the loop who manually inspects the part, be it doors, outer body covers, hoods etc. This is done because it is a high-risk situation with no margin for error. The human spends a considerate amount of time on each part, going through the complex geometry of the part and giving approval based on their judgement.

What we propose is a new paradigm in vehicle body inspection. We intend to install an array of cameras that are strategically placed at the outset of the line where the parts come after there are pressed. We can have passive alignment tools which orient the part and prepare it for the camera array. Then the parts are run through the camera array which clicks a photo of the part from multiple angles. The images are all processed by a computer by the use of Computer Vision algorithms which can instantaneously make a decision based on the images whether the part is defective or not.

This solution will speed up the car body inspection process and eliminate the human in the loop which will lower the chances of errors in human judgement. This solution can be further improved by the use of advanced Machine Learning and Deep Learning algorithms which can work faster than traditional Computer Vision algorithms but also require significant computing resources. These camera sensors form a part of the larger Industry 4.0 and multiple such lines of production give rise to their own Industrial Internet of Things in every manufacturing plant.

Index

S. No.	Title	Page No.
1	Abstract	2
2	Goal	4
3	Problem Definition	4
4	Scope of the Project	6
5	Objectives	6
6	Organization of this Report	7
7	Manufacture of Car Body	7
8	Causes of Defects in the Stamped Parts	15
9	Unit Manufacturing Process of Car Body Manufacturing	16
10	Our Proposal to Automate the Inspection Process	19
11	Image Processing Approaches	22
12	Simulation	30
13	Discussions & Conclusions	34
14	Smart Manufacturing Recommendations	34
15	Acknowledgements	34
16	References	36
17	Resources	37

2. Goal

The automobile industry is a highly regulated industry. These regulations act as an impetus for the manufacturers to exercise strict quality controls on the vehicles they send out to the public. Of the many regulations the automotive industry needs to abide by, the IATF 16949 technical standard, formerly known as ISO/TS 16949, is an important one since it deals with the following aspects of the industry. [1]

- Process efficiency and effectiveness
- Customer satisfaction
- Continuous improvement
- Defect prevention
- Supply chain optimization

The vehicle industry has always led the way forward in terms of innovation. So when we found out that there was one aspect where they were held back from total automation, we were taken aback. The entire car body manufacturing process contains several processes, right from procurement of the right type of raw materials to assembly of all the parts. The area we focused on us the car body manufacturing process.

Car body manufacturing is a very important aspect of the automotive industry and is dealt with with highly rigorous standards. It can be broken into multiple smaller Unit Manufacturing Processes (UMPs). These will be delved into depth in the coming sections but for a brief introduction, it contains three main UMPs. The sheet rolls are blanked into desired sizes, and the blanked rolls are sent to respective presses where they are stamped into desired shapes, be it a door, the bonnet (hood), trunk etc. And once the parts are stamped they go through the inspection process.

The goal of this project is to assess the current methods of inspection and provide alternative approaches to the inspection process which will help with automating the whole process. The help with our solution we delve into other explanations which will help the reader to get a high-level understanding of the entire car body manufacturing process and connect the dots regarding the novel inspection process which we propose.

3. Problem Definition

Before we define our problem, let's first understand why the need for inspection of parts arrives in the first place. In most cases, the outer body of a car is usually made with the help of steel alloys. Steel, while having a good tensile strength isn't an easily malleable material. So when we pass the parts through the stamping process, there is a high chance of the material cracking and developing defects under such huge pressure from the press. If these cracks go unchecked, they will cause severe problems to the end-user and compromise the safety of the car which is, in turn, a liability to the humans travelling in it. To reduce the liabilities caused due to defects in the car body, companies go to great lengths to ensure that the part produced after the stamping process is fit for further operations and be installed into the assembly.

Currently, in most industries, the inspection of body parts after the stamping process as mentioned above is usually done manually. At the end of the conveyor, where the parts are received after manufacturing, one (or more) human operators are placed who will assess each part manually by the use of sight and touch. They look over and feel the entire periphery of the part and based on their assessment make a judgement as to whether the part is defective or not. This method has an inherent flaw since humans are prone to lapses in judgement. They may not be having a good day and on that day, they may classify more parts as defective even though they may not be defective. Or if they are too joyous, they may do the opposite, classify parts which may be defective as totally perfect parts. The operator’s skill level also affects the way they inspect and classify parts. Sometimes, improper vision and health other health conditions may also affect the way parts are inspected. To state an industry example, In the Swedish automotive industry, about 20 - 45% of the total vehicle breakdowns are caused by human factors and errors due to inaccuracies in handling, inspection and preventive maintenance. [2]

To address this issue the biggest car manufacturer, Volkswagen, in partnership with the camera and lens manufacturer Zeiss has come up with a technique for inspecting car parts by the use of high-quality cameras attached to the ends of robot arms. [3] These robots move around the entire crosssection of the part and take videos which are then analysed by an image processing system. Though this is a good replacement for human inspection and it helps reduce most of the quality concerns raised in the section above. The only concern is that it is too expensive of a setup. To dedicate at least three to four robot manipulators just for inspection will drive up the cost of the entire process at least ten to fifteen-fold than it currently is. Many industries, especially those based in developing countries like India where labour costs are lower, may not be able to afford it for their plants since the difference in cost to switch to such a system will be much higher. And the amount of area the Volkswagen-Zeiss setup covers may not be available on shop floors where making space for even a single machine is a Herculean task.

Taking all these factors into consideration, we propose a simple and efficient process to help automate the inspection process of parts after their manufacture. We propose to install a multi-camera array system in place of the human operator, which will take images of the parts from various orientations and by running these images through robust image processing algorithms, we can quickly decide if a part is defective or not. This proposal solves three major concerns,

a. It removes the human from the loop, thereby reducing the chances of false classification of parts
b. It improves the efficiency of parts inspection as the vision-based inspection process will be faster than the human inspection process
c. By use of this process, after initial challenges are worked through, it will save the manufacturers capital which can be better used in other areas such as R&D, using better materials etc.

4. Scope of the Project

We realize that the automotive industry is quite huge with thousands of intricate and individual processes which require detailed focus in their own right. Our analysis, as mentioned above, is only pertinent to the car body's parts' inspection process. While we do get deeper into the various aspects of automotive manufacturing, it only provides the reader with the basic background needed to understand various processes involved in the manufacture of the body parts. The body parts created in this process are usually the doors, hood, the outer body, trunk etc. For our analysis, we treat them as a single entity undergoing similar operations because in real life the only difference in the parts is the shape of the die doing the stamping to give it that shape.

5. Objectives

- On a high level, understand the different processes involved in the manufacturing of an automobile
- Select and highlight the section related to the car body manufacturing process for further analysis
- Breakdown the car body manufacturing process into respective Unit Manufacturing Processes
- Create Unit Manufacturing Process Diagrams to properly understand what goes into each sub-process
- Study the current methods involved in the inspection sub-process of the car body manufacturing
- Propose new solutions to automate and improve the efficiency of this process

- Design a 3D Discrete Event Simulation to help visualize your proposal and also to provide required insights to support your proposed solution

6. Organization of this Report

This report is broken into parts which describe in-depth the relevant aspects. It begins with setting the context with the Abstract, discussing the Goal of the project, Defining the Problem we are trying to solve, acknowledging the limits of the report through the Scope and setting out Objectives of how we are going to achieve the aforementioned goals.

The subsequent part of the report will be further broken into sections mentioned below.

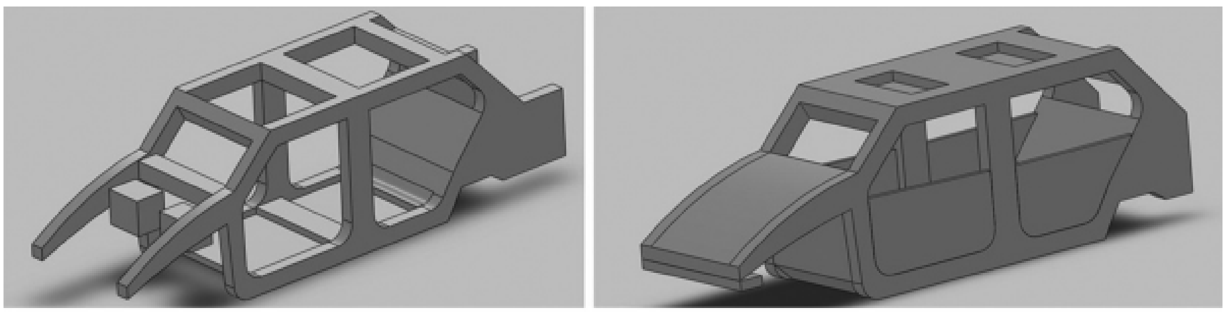
a. Brief Introduction to the automotive manufacturing industry
b. UMPs of the car body manufacturing
c. Manual Inspection
d. Our proposal for the project
e. Image Processing aspects
f. Simulation
g. Discussions & Conclusions
h. Acknowledgement
i. references

7. Manufacture of Car Body

Anatomy of an automobile and its functionalities:

Customers today judge an automobile's worth based on its construction, mobility capabilities, look, and other features such as infotainment etc. This reality drives automotive engineers to create engineering measures that quantify each of these views, allowing them to improve their designs, evaluate their vehicles against their competitors and, most crucially, comply with regulatory requirements. Crash safety refers to a vehicle's ability to absorb dynamic energy without damaging its occupants in the event of a collision, whereas durability refers to the likelihood that the structure will work without failure for a given period of time or frequency of use. The noise, vibration and harshness describe a structure's ability to absorb various degrees of vibration and provide a desirable (planned) level of comfort. The ride and handling qualities of the vehicle, as well as the durability of the driveline and power-train components, determine its mobility. The vehicle's performance is influenced by the materials used (weight and stiffness) as well as the design geometry (centre of gravity placement).

The Powertrain, chassis, exterior, and interior trims, and the vehicle bodyshell are the key components and subsystems of the vehicle. The prime mover (an internal combustion engine or an electric motor), the gear system, and the propulsion and driveshafts make up the powertrain, whereas the chassis houses the suspension and steering components, as well as the wheel, tires, and axles. The front and rear end, the door system, and the cockpit trim are all made up of internal and exterior trims. Finally, the body in white consists of the closures (doors, hood, and tailgate) as well as the frame as seen in figure 1 below.



Body Structure　　　　Body in White

Figure 1 - The first one is the vehicle body structure without closures, second is the complete vehicle body with closures in white.

We may conclude that design strength, stiffness, energy absorption, dent resistance, and surface roughness are used to evaluate vehicle performance. Designers should consider manufacturability before choosing a material or designing a certain shape. Manufacturability is defined in terms of design formability, joining ability (weldability and hemming ability), attained surface finish and surface energy, and total cost in the context of an automotive body structure. This reality necessitates a greater grasp of automobile manufacturing processes and systems since they will ultimately determine the design's overall cost, final shape, functionality, or design validity. The manufacturing operations in the automotive industry can be broken down into two categories: manufacturing systems and processes.

Assembly plants and power-train plants are the two types of plants used in the automotive manufacturing process. Both of these plants specialize in various transformational processes, converting various raw materials into finished parts. Both are time-synchronized to allow their ultimate outputs to be integrated into entire vehicles.

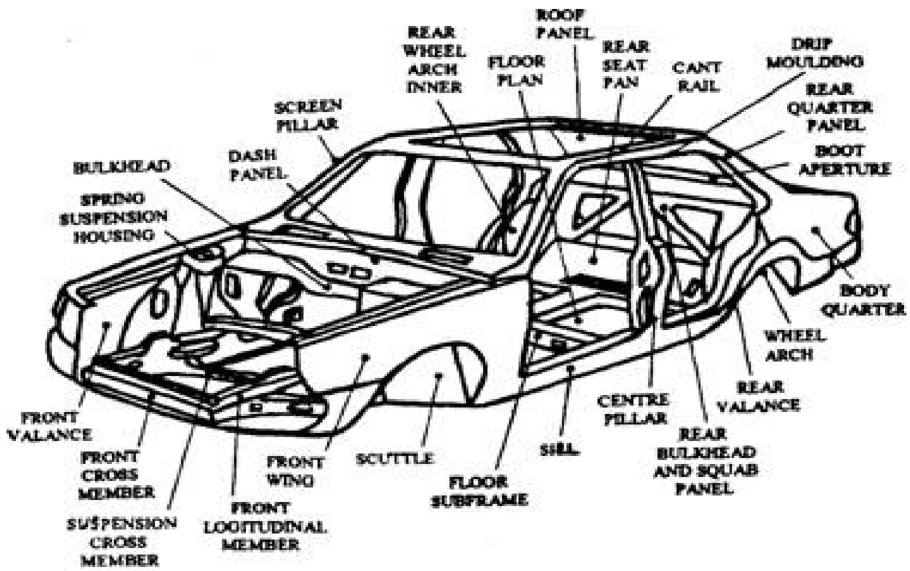


Figure 2 - Anatomy of Automobile

The automotive assembly factory is only the last step in the manufacturing process, as it is here that parts from over 4,000 outside suppliers, including company-owned parts suppliers, are brought together for assembly, usually by truck or railroad. The parts for the chassis are delivered to one location, while the parts for the body are unloaded at a different location.

Steps involved in the production of an automobile

- Stamping is the first step in constructing a car, and it entails transforming raw materials such as steel sheets into body parts. To begin, stamping and metal forming are shaping, trimming, embossing, flanging, piercing, or restriking a metal blank (usually steel sheet metal). Steel is closely related to the automobile industry because many parts of a car are composed of steel. Like hoods and fenders, external car components are commonly created utilizing metal stamping procedures.

- Second, Automotive Joining (also known as fusion joining) entails the melting and coalescence of two materials. Resistance spot welding, laser welding, and arc welding are all common instances in car body construction. Solid-state joining does not necessitate the melting of materials. The workpieces, on the other hand, are frequently heated.

- Next, automotive painting refers to the application of paint on automobiles for both protection and adornment. The most extensively used paint is water-based acrylic polyurethane enamel paint, which has the advantage of lowering paint's environmental impact.

- The final phase in the production process is assembly. The mechanical components, the driving position, mirrors, and the vehicle's interior trim are all constructed and mounted at this point.

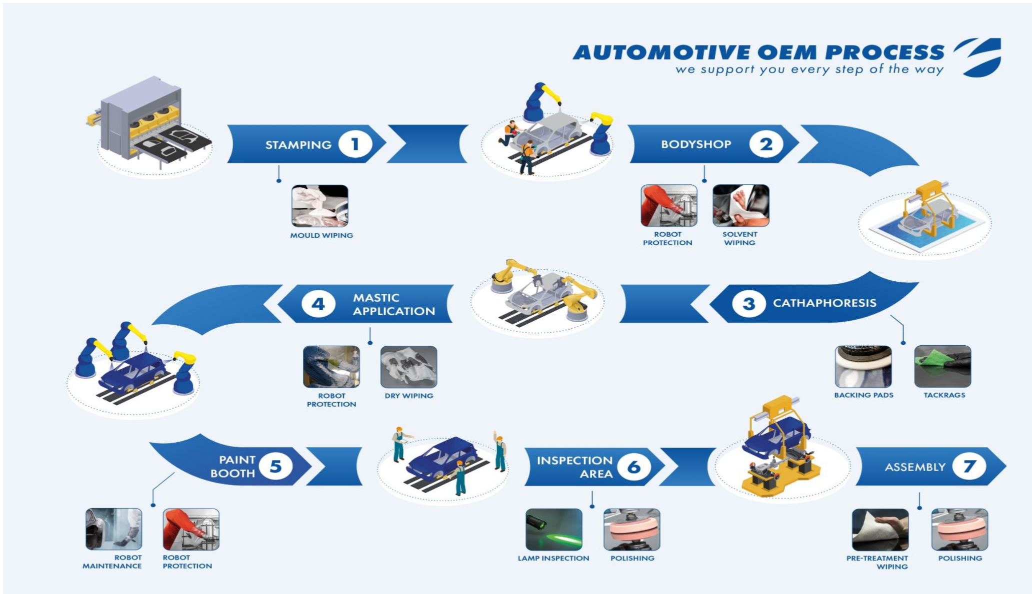


Figure - 3 The Automotive Manufacturing Process

Let us delve into each aspect of the automobile manufacturing process a little deeper. This will help with two things. One, to understand how the procedure is done, help with creating the Unit Manufacturing Processes later on. Although there are more operations which are performed on the parts such as joining, painting and assembly of parts, we are only concerned with those operations which are within the scope of our project.

Step 1 - Blanking:

Blanking is a manufacturing technique that involves putting a coil of sheet metal into a press and a die to generate a flat shape. This is the first step in our manufacturing process. The metal sheet is placed on the blanking die and processed through a cavity where the shaped press punches out the steel by releasing a large amount of pressure at a rapid speed.

When you choose to use blanking metal, you get a lot of benefits. Because of its operations, blanking allows you to obtain more products while using less material. Because the machines are set up to manufacture blanks as near together as feasible, waste is considerably reduced.

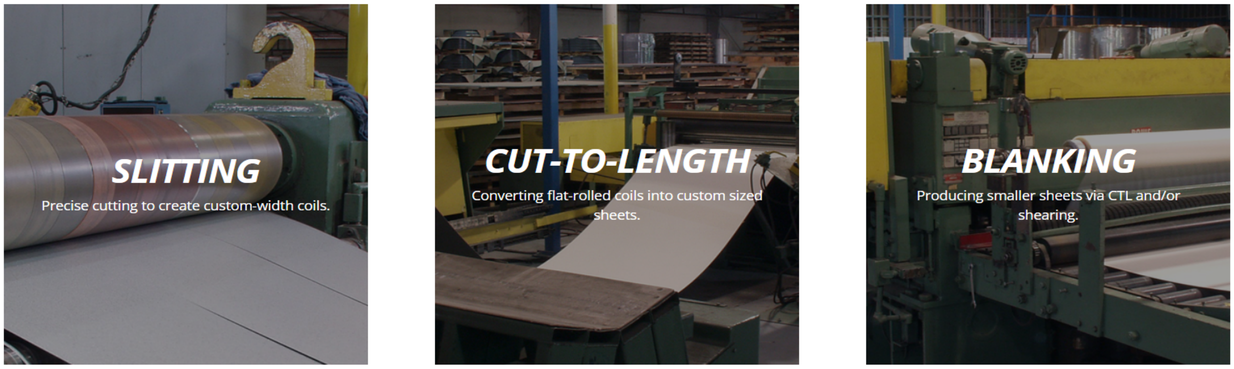


Figure 4 - Pre-Blanking processes

Figure 5 - Blanking Process of automobile manufacturing

Step 2 - Metal Stamping:

Stamping of sheet metals is described as the process of employing a die and a mechanical press to change the shape of a sheet metal blank into a usable shape in the plastic deformation state; stamping is considered a net shaping process. Different types of stamping such as Progressive die stamping, Multi-station stamping, and Tandem stamping are the major components of an automation stamping production line. They are utilized to make various automobile sheet metal parts due to their distinct features. They play a critical part in automobile automation and efficient production systems due to their distinct benefits.

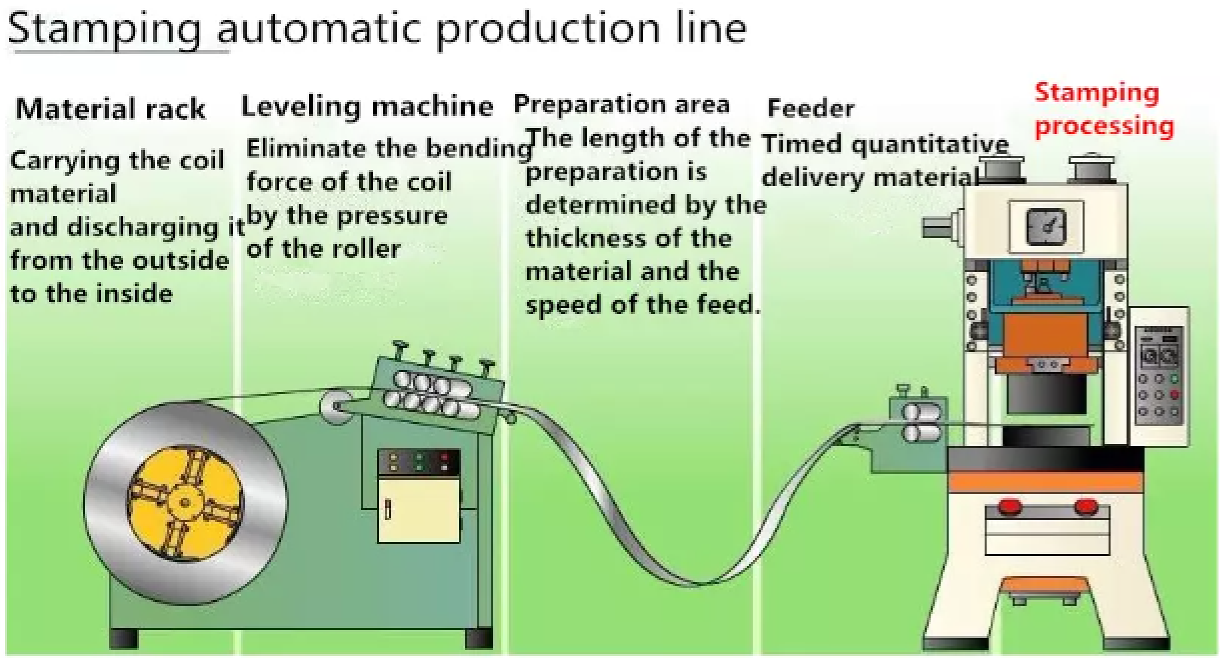


Figure 6 - Stamping automatic production line of manufacturing of automobile parts

Factors to consider while stamping automated production lines:-

- Product material: Includes material kind, form, hardness, and other characteristics to assess coil or sheet forming options.
- Material thickness: When choosing the tonnage of the press machine and the matching shape of the feeding mechanism, synergistic materials are taken into account.
- Monthly supply and demand: Evaluate production capacity, define production tempo, and weigh automatic line types selection.
- The volume and shape of the stamping product: The mould design method and the accompanying stamping automation production method are thoroughly analyzed based on the modelling complexity and product quality criteria.

In industrial manufacturing, injection moulding, blow moulding, extrusion, die casting or forging, smelting, stamping, and other methods are used to create various moulds and tools for the required goods. Automobile moulds are the broad term for the stamping of all the stamping pieces on a car body in a narrow sense. Following that, we'll show a few photographs to give everyone a better visual comprehension of the automobile stamping die. The green ones in figure 7 are vehicle moulds; during the manufacturing process, the die and the press machine work together to press the steel plate. Various moulds punch out various automotive sheet metal parts. The acquired steel plate is first sent to the stamping line to be cleaned by the washing machine, and then transferred to the next station, the first station for stamping, by the robot arm. The steel plate is then delivered to the next station for cutting, punching, and folding. All of these tasks are carried out automatically. Because of the quality inspection and loading of stamped sheet metal parts, the final receipt is done manually. A stamping production line in a car factory also has five stamping presses.

Figure 7 - Parts of the automobile made with stamping

The primary function of an automotive stamping shop is to press steel sheets into various sheet metal parts using various moulds placed on a stamping machine. In industry, there is still a lot of work to be done to assure the normal manufacturing of sheet metal parts, such as equipment and mould maintenance.

Why do we need Metal Stamping for Automobiles?

Metal stamping manufacturing procedures may produce solid metal components and forms rapidly and neatly. Specialized dies are used to crush metal sheets into precisely the proper shape. Metal stamping for parts like fenders and hub caps is advantageous because the dies may be reused to produce consistently sized and shaped parts that meet tight requirements and tolerances. Metal stamping has several major advantages, including cost-effectiveness, material efficiency, automation etc. Metal stamping presses and dies can generate a variety of items from a variety of metals. Aluminium, copper, and steel are some of the most widely utilized metals in stamped vehicle parts. Each metal has its own characteristics that make it suitable for specific uses.

Step 3 - Inspection of parts:

Quality control is necessary for all industries, but it is especially important for makers of automobile parts to ensure that every product that leaves the factory is of the highest quality. New cars today are more dependable than ever before. Manufacturers who are an important part of a car's supply chain must spend on top-quality control checks, just as carmakers do. Despite the fact that the car industry has a very limited margin for error when it comes to safety and manufacturing efficiency, stories of costly recalls continue to circulate.

In the automotive business, quality control is not only necessary to assure reliability, but it may also assist to cut costs. When cheaper alternatives are easily available, investing in high-quality items may appear to be more expensive, but consider the future cost of recalls and accident compensations, which can be costly and dangerous for both drivers and producers. By verifying that all automobile components fulfil critical industry standards, independent quality control inspections can discover and repair any flaws before the product is marketed to manufacturers and customers. Quality control is a lengthy process in the automobile industry, both in terms of bringing a new model to market and ensuring that every car created during the entire manufacturing cycle meets the highest possible standards. Prototype models are created and tested to identify any mechanical flaws or difficulties that need to be addressed. The design will go into production when the prototypes have been reviewed, and quality control will continue with each car. Following the completion of the construction work, each automobile is inspected and tested for any additional concerns such as fluid or air leaks, mechanical faults, and to check that the vehicle has been correctly assembled.

Process of Inspecting the parts:

Visual checks will be conducted to look for any problems, as even minor flaws could result in accidents or costly recalls. The cylinder head and block are visually evaluated for an efficient and long-lasting engine, with an emphasis on the oil boreholes, oil lines, and cooling channels. Second, the brake system is the vehicle's most critical safety component, and the master cylinder, brake calliper, brake discs, and fluid must all be visually verified during the manufacturing process. To improve safety and usefulness while lowering the risk of recall, it is necessary to maintain the quality of the automobile parts utilized in these areas.

It is critical that all parts used in the assembling process meet quality standards. The list continues with automotive interiors and exteriors, powertrain components, brake fittings, steering systems, wheel systems, undercarriage components, body parts, travel accessories, the full range of electrical instrumentation accessories, any specific modification such as toughened bodywork and glass, security systems, comprehensive accessories.

Figure 8 - Inspecting process of manufactured parts in the automobile industry

8. Causes of Defects in the Stamped Parts

Now that we have understood the operations that go behind the manufacturing of parts, let us understand why we are inspecting the part in the first place. The Stamping process is done on steel. Steel isn't as malleable a metal as Aliminium for example. The malleability of steel causes it to have defects in them.

The extent to which a sheet metal can be moulded or worked into a certain shape without failing (cracking) or forming other undesirable traits is known as formability (e.g. Lueder bands). The stamped piece's quality is usually determined by the appearance of the panel, the strains that occur (patterns, directions), and the final proportions. The final geometric qualities of stamped panels, which include one or a combination of four primary geometric shapes: plane, tunnel feature, dome element, and irregular features, can be used to quantify such criteria. Furthermore, the strain values and gradient were obtained to characterize the metal flow pattern. The creation of a split or crack in shaped panels is the most serious of stamping flaws. Since the 1950s, researchers have attempted to create formability measurements and theories with a focus on sheet metal split or fracture avoidance.

Main types of stamping defects

- Splitting in the stamped panel: local necking rupturing away from the edge of the stamped panel.

- Splitting at the panel's edge: rupturing near the stamping's edge due to lower deformation capacity at the edge due to shear zones (edge burrs and cracks).

- Wrinkling: waviness on the surface caused by compressive plastic instability.

- Shape change: induced by distortion and spring-back, this is the elastic recovery within the panel. Depending on whether it occurs after the first or second unloading of the panel from consecutive stamping procedures, the spring - back spring - back or a second spring - back.

- Low stretch: The produced panel's work hardening performance is reduced, lowering its dent resistance.

- Surface soft or low oil canning load ability: induced by residual strains from sequential stamping's various loadings.

The mechanisms that cause defects can be summarized as follows: defects caused by severe stresses and strains (as in the case of splits); stress and strain gradients; panel deformation history; and residual stresses after unloading from the die cavity.

Now that we have studied the various defects caused in the stamping process, we understand that working towards reducing the defects is an important engineering and materials problem. Work on it is constantly underway. What we are trying to work on in this project is to accurately catch all the defective parts after stamping in the inspection phase.

9. Unit Manufacturing Process of Car Body Manufacturing

Creating a product or component frequently necessitates the coordination of several operations. Individual procedures (such as casting, machining, and surface treatment) necessary to generate completed goods by changing raw materials and adding value to the workpiece as it becomes a finished product are referred to as "unit processes." The Manufacturing process of transforming raw materials, which are often provided in simple or shapeless forms, into final products having a specified shape, structure, and qualities that meet certain specifications.

Breaking down manufacturing processes into Unit Manufacturing Processes (UMPs) helps in many ways. It was initially developed as a tool to study the overall sustainability of the process by understanding the sustainability of each sub-process. But we can use it for other analysis purposes too, not just to analyze sustainability.

Let's create the Unit Manufacturing Process for each of the operations involved in the manufacture of the car body parts. These are the same operation we mentioned in the previous section. For each operation, we also draw UMP diagrams which help us get an idea of the inputs to the system, the outputs from the systems, the resources used and the controlling factors for each process.

1. Unit Manufacturing Process of BLANKING Process:

This is the first Unit Manufacturing Process involving the slitting and length-cutting of raw materials (metal sheets) into small sheets that fulfil given requirements. This process will have sheet metal coil, Lubricants, and Energy inputs. The sheet metal of the desired size is produced as the output.

For this process, the Controlling Factors are CAD Files, PLM Documentation, Production Plan, Equipment Specs, and Safety Documentation. The required Resources for this process are a Cutting press, Blank Blades, and Supervisor (optional).

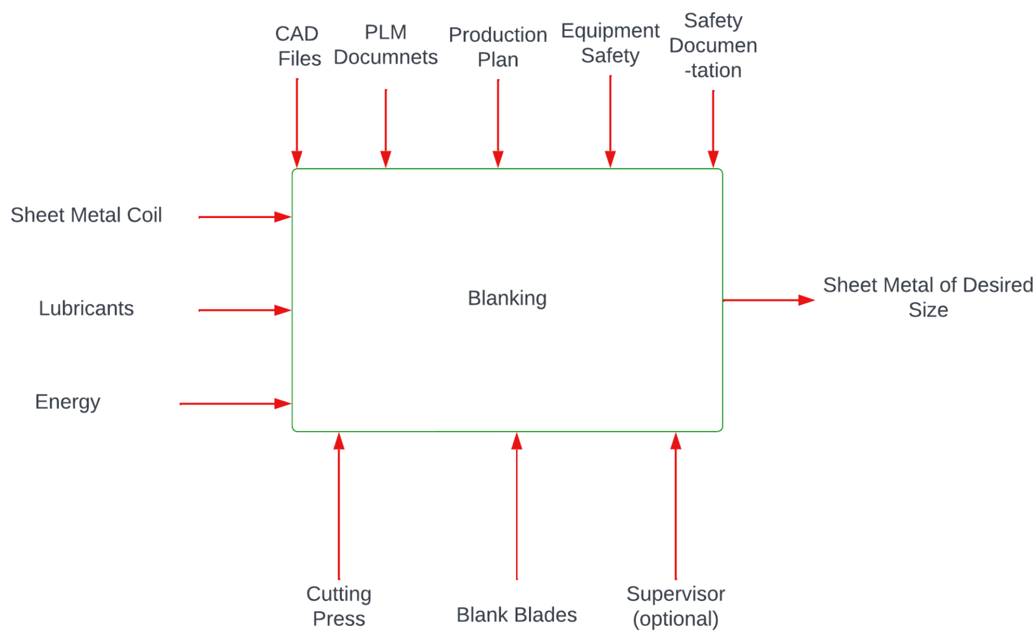


Figure 9 - Unit Manufacturing Process Diagram of Blanking

2. Unit Manufacturing Process of STAMPING Process

Manufacturing involves the conversion of raw materials (metal sheets), usually supplied in sheet forms, into finished products with specific shapes, structures, and properties that fulfil given requirements. This is the second UMP of our manufacturing process. The inputs for this process are the outputs of the UMP1 of the Blanking process, which is Sheet Metal with desired size, Lubricants and Energy. The outputs which are produced are part with desired shape and metal waste.

For this process, the Controlling Factors are CAD Files, PLM Documentation, Production Plan, Equipment Specs, and Safety Documentation. The required Resources for this process are a Die Machine, Press Machine, and Supervisor (optional).

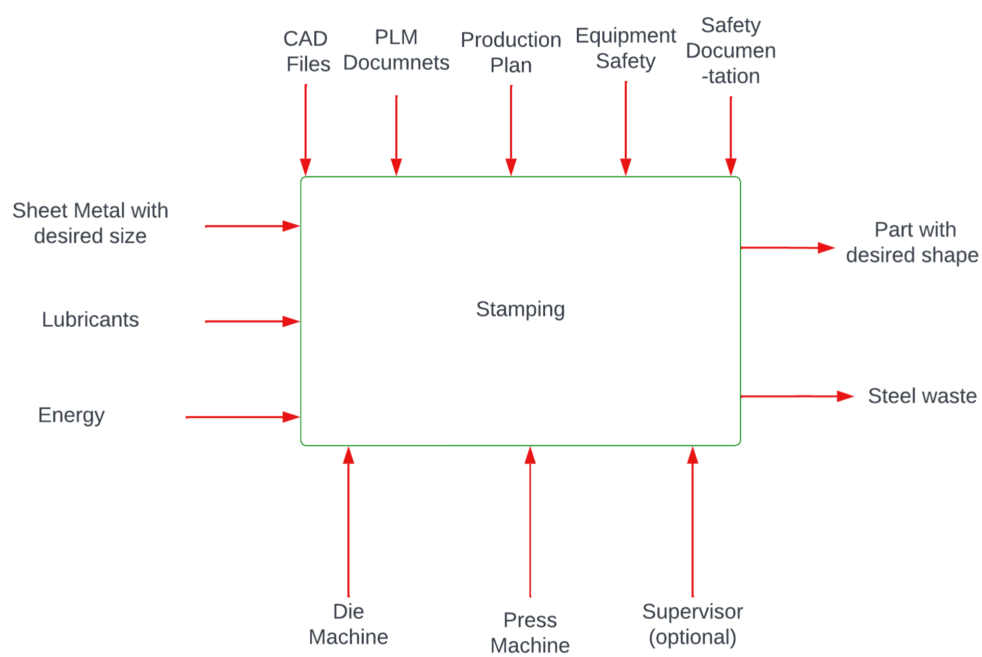


Figure 10 - Unit Manufacturing Process of Stamping

3. Unit Manufacturing Process of Inspecting the parts

This is the third UMP of our manufacturing process. The inputs for this process are the outputs of the UMP2 of parts of the desired shape. The outputs which are produced are parts with desired perfect parts and defective parts.

For this process, the Controlling Factors are inspection guidelines, Production Plan, Equipment Safety, and Safety Documentation. The required Resources for this process are a Human Being, Support Structure (optional).

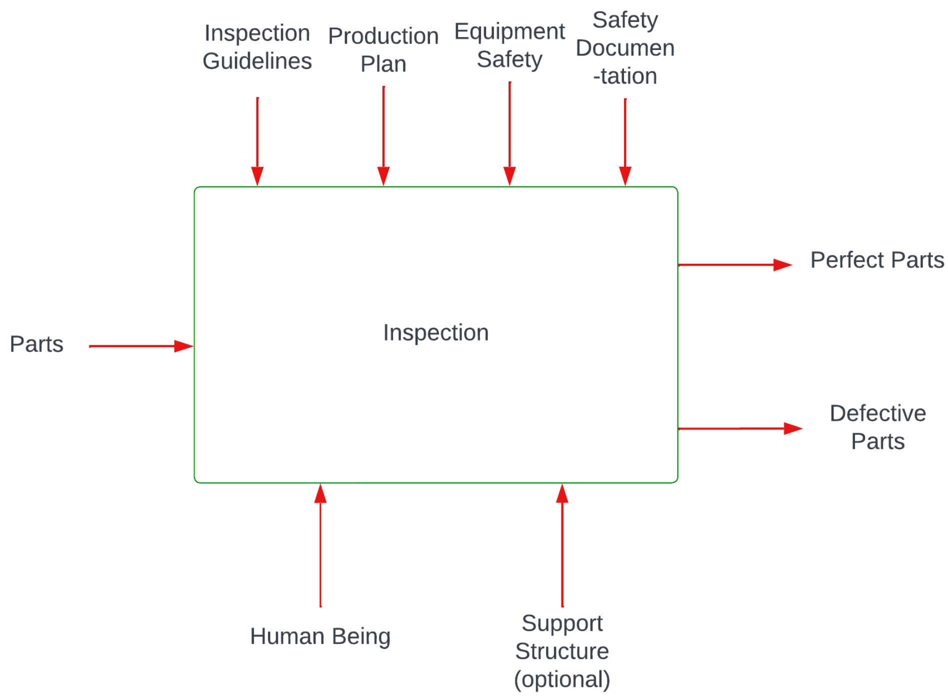


Figure 11 - Unit Manufacturing Process of Inspecting the parts

10. Our Proposal to Automate the Inspection Process

As we have seen, the parts are manually inspected once they are manufactured. We have also discussed the drawbacks that follow with the manual inspection of parts. So here we propose ways to automate the process and improve the efficiency of the procedure.

We propose to remove the human from the loop and replace them with a multi-camera array system. After the stamping procedure takes place, the parts will leave the stamping station on a conveyor belt system. So before it arrives at the inspection station, we can make use of passive orientating mechanisms to align the part properly before it is sent to the inspection station. Once the part reaches the inspection station, right under the camera array system, all the cameras take the image of the part and they are sent to the image processing workstation. The image processing workstation is equipped with computers of high processing power which process the images by the use of custom developed algorithms based either on traditional computer vision algorithms or Machine Learning techniques or a hybrid technique which uses both of them. The robustness of each of these image processing techniques will play a huge role in this since some parts have simple geometries such as the hood of the car can be done directly by the use of traditional computer vision algorithms, whereas some parts such as the trunk, might need a more robust hybrid combination of traditional Computer Vision with Machine Learning for inspection.

Once the parts are inspected using the vision-based system, they can be tagged as either a good part or a defective part and this information can be printed onto the part by the use of laser printing and the parts can be sent for further processing where the defective parts can be removed from the lot and sent back to the plant where it can be reprocessed and made in sheet metals without much wastage.

The inspection process can be made more robust with the following methods

a. By the use of high-quality industrial vision-based cameras which can capture even the tiniest of details
b. Having a sensor fusion setup where we attach a 2-D or 3-D Lidar which captures the 3-D point cloud of the object and this information can be used in conjunction with the images captured by the camera to produce reliable results. Especially for those parts which have too many intricate details. The only concern with this option is the need for better sensor fusion technologies which might need more research and development.

The Benefits of this approach

By the use of this approach, we aim to achieve the following things

a. Eliminate most of the inaccuracies in the part inspection process since it is now an automated process which isn't prone to lapses in human judgement and they will always produce repeatable results thus offering us a high probability of detecting the defects only in those parts which are defective
b. An average human being takes anywhere between 10-15 seconds to inspect a part. This may increase for parts with intricate details. Whereas this proposed system is estimated to take anywhere between 5 - 7 seconds to inspect and classify the part to be either defective or not. That's an efficiency improvement of at least 2 times over the manual inspection process.
c. We can create a central repository of data and algorithms which can just be simply accessed by plants in other parts of the country/world where similar parts are manufactured and the entire R&D doesn't need to be repeated everywhere. Simple changes can be made as required for each plant.
d. The human removed from this section can be put to better use in different areas of the shop floor which requires either higher human involvement. They can also be upskilled and put to use in certain R&D groups as required too. They can also be used in the research and development of the vision-based inspection system where their expertise in inspecting parts over the years can be used as insights

when designing the image processing algorithms. We can even deploy the human in the assembly section where all the parts of the car are assembled as that is a highly human-intensive activity.

Possible drawbacks of this approach

Although this procedure of automating the part inspection process has several benefits, these are the drawbacks we estimate it comes with.

a. Requires the automotive companies which invest in research and development to develop the technologies required for this proposal. Mainly the image processing techniques. Also in the development/procurement of high-quality cameras needed for this. They also will need to work on the research and development for the fixture of the camera array system.
b. The time required to develop and test the real-world implementation of the idea may time some time, so initially, the companies rely heavily on producing accurate results. Only them can it be used in all its manufacturing plants
c. Hesitancy in adopting newer approaches either by the companies or by labour unions which fear that they may lose their jobs to automation. Companies need to provide alternative opportunities for the humans removed from the inspection process.

As per our proposal, the inspection sub-process is being altered, replacing the human being with a vision-based system for inspection. An updated UMP for the same will be as follows.

New Unit Manufacturing Process of Inspecting the parts (Vision-Based method)

This is the updated version of the third UMP of our manufacturing process. The inputs for this process are the outputs of the UMP2 of parts of the desired shape. The outputs which are produced are parts with desired perfect parts and defective parts.

For this process, the Controlling Factors are inspection guidelines, Production Plan, Equipment Safety, and Safety Documentation. The required Resources for this process will witness a change here. Instead of a human, we use a Camera Array System, an Image Processing System, and a Support Structure (optional).

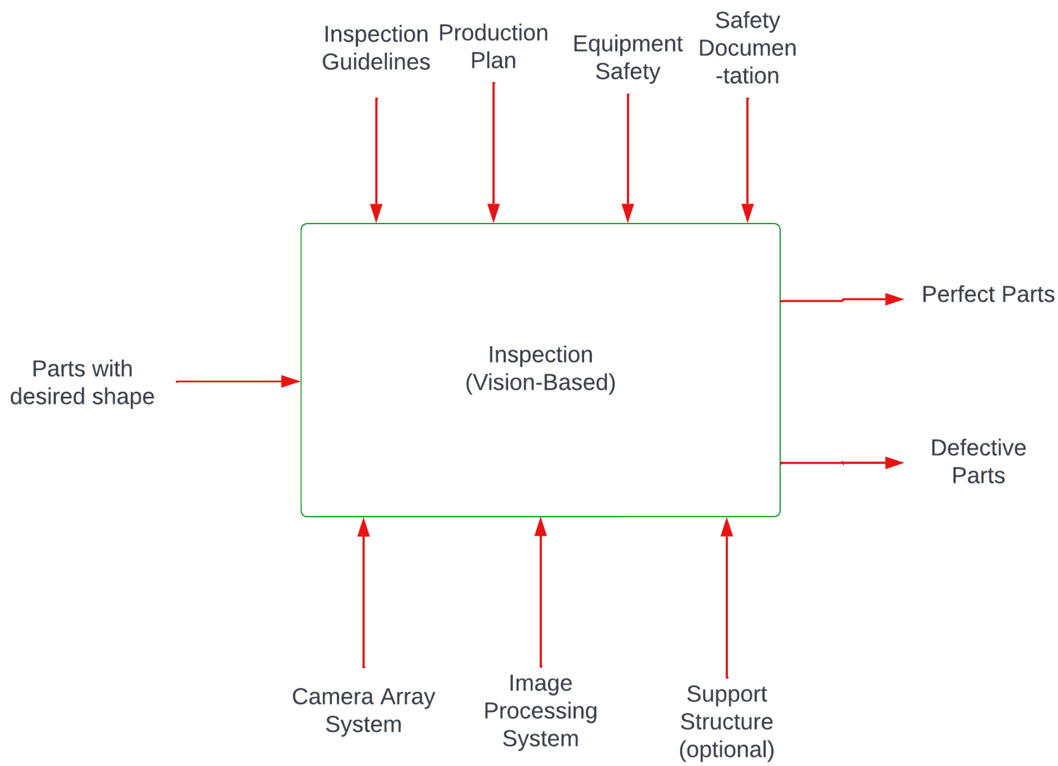


Figure 12 - Unit Manufacturing Process of Inspecting the parts (Proposed Vision-Based method)

11. Image Processing Approaches

Computer Vision

Computer vision is a constantly evolving field of Artificial Intelligence that extracts crucial information from video feeds, digital images and/or other visual inputs. It enables computer systems to take actions or recommendations based on the extracted information. More succinctly put, Artificial Intelligence helps the computer to think and Computer Vision enables the system to observe and understand. [5]

The application for Computer Vision for the proposed task falls under the quality control systems type i.e automatic detection of production failures or part defects during the inspection stage.

Computer vision algorithms

- Contour Detection: The use of contour detection is generally to find borders/boundaries of objects and localize them with relative ease in an image. The main application of contour detection in car part defect detection is background/foreground segmentation. Contours are detected by marking changes in image colour as contours.

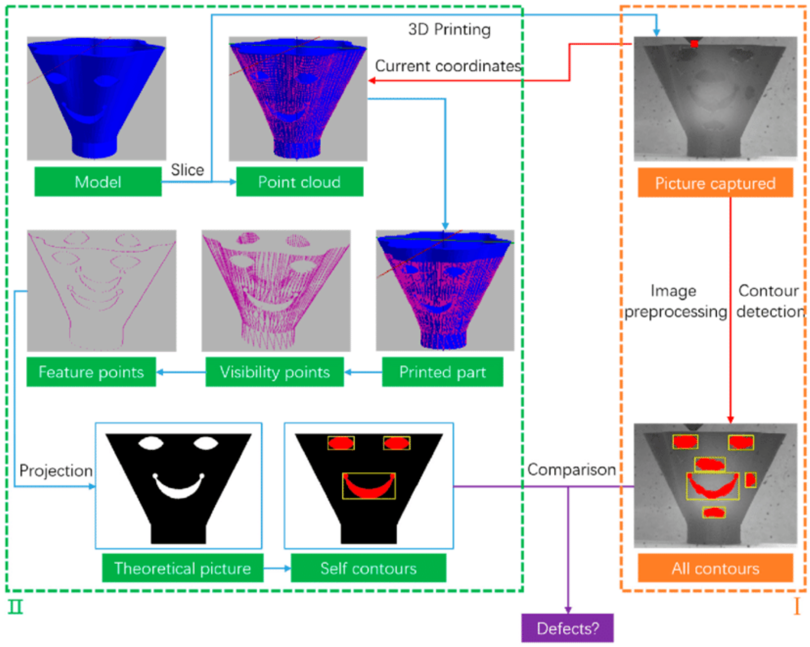


Figure 13 - Processing of parts; Contour detection [7]

- Edge and Line Detection: Edge detection is an image processing approach for detecting item boundaries within images. It works by detecting brightness variations. Discontinuities are sharp changes in pixel intensity that define the edges of objects in a scene. The operator's shape determines a certain direction in which it is most sensitive to edges. The search for horizontal, vertical, or diagonal edges can be optimized using operators. Examples of common edge and line detection algorithms include canny edge detection and Sobel operator. We can apply the following signal with an edge shown by a jump in intensity.

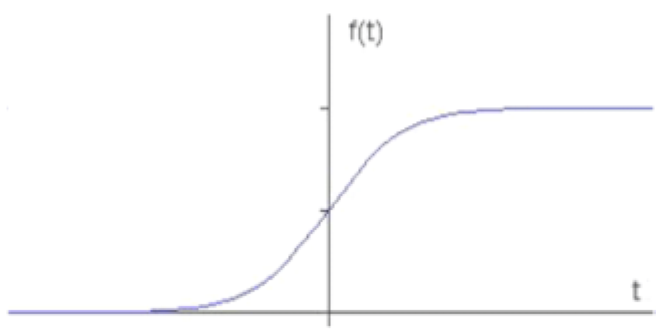


Figure 14 - Signal Applied to edge detector

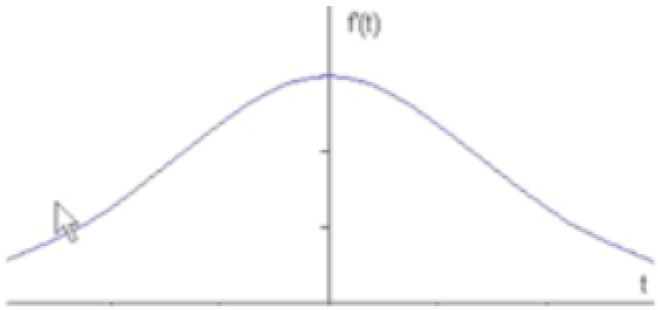


Figure 15 - Gradient first derivative of the first signal.

The gradient obtained from the signal applied to the edge detector is shown above. According to the Sobels approach, this method of locating an edge belongs to the "gradient filter" family of edge detection filters. [7]

- Corner Detection: Corner detection is a method for extracting certain features and inferring the contents of an image in computer vision systems. The intersection of two edges is what a corner is. In a local neighbourhood of a point, a corner can alternatively be described as a point with two dominating and different edge directions. Li suggested a contour transformation-based Harris multi-scale corner detection technique. The identified corner points are more regular and reasonable, making them useful in a variety of disciplines such as image mosaic. [8]

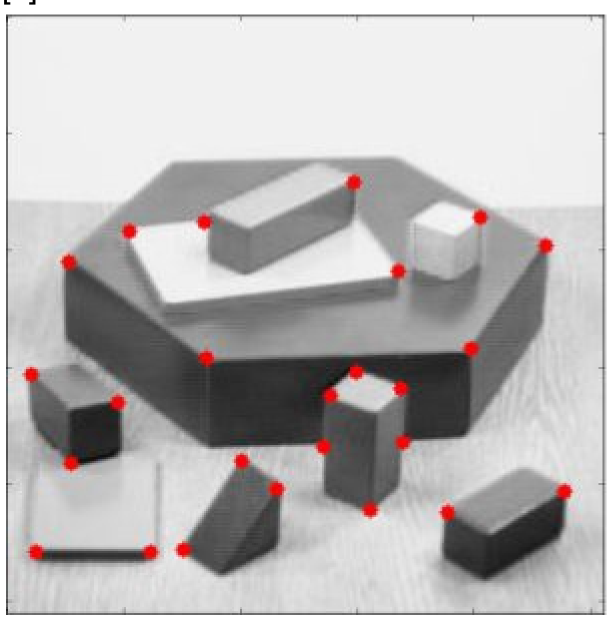


Figure 16 - Harris Corner Detector [9]

- Feature Detection: A feature is a piece of information about the content of an image in computer vision and image processing, usually concerning whether a certain portion of the image has certain attributes. Specific structures in the image, such as points, edges, or objects, might be used as features. A generic neighbourhood procedure or feature detection applied to the image could potentially produce features. Other elements include motion in image sequences, as well as shapes defined by curves or the boundaries between separate image sections.

Now, let us look at the usage of feature detection methods like SIFT in sheet metals. SIFT stands for Scale-Invariant Feature Transform and was first presented in 2004, by D.Lowe, University of British Columbia. For the following SVM classifiers, SIFT can be utilized for both defect point detection and feature description. Because of its ability to extract and describe features, the SIFT has been used in a variety of applications. The scale space and orientation histogram-based descriptor are the major sources of its potency. The picture below displays a 32-feature histogram that has been expanded four times, yielding 128 features for one feature point. [10]

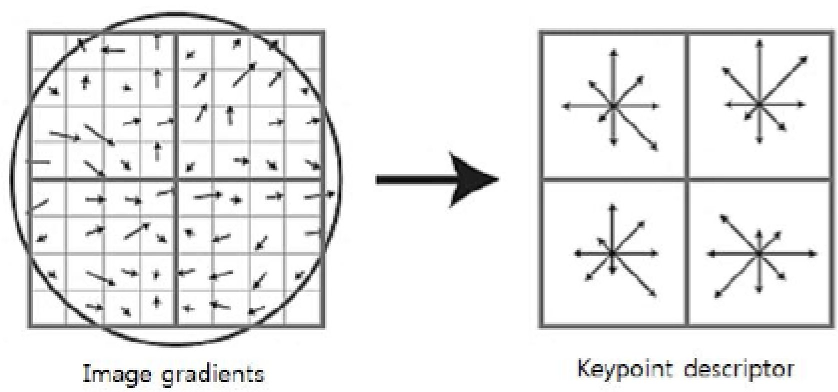


Figure 17 - Gradient Orientation Histogram Descriptors

Using Principal Component Analysis, the following study increases the descriptive power by compressing the original 128-dimensional characteristics into 20-dimensional features. We can extract a large number of important points from a single image using the SIFT. The figure below depicts a large number of significant spots found in defect regions.

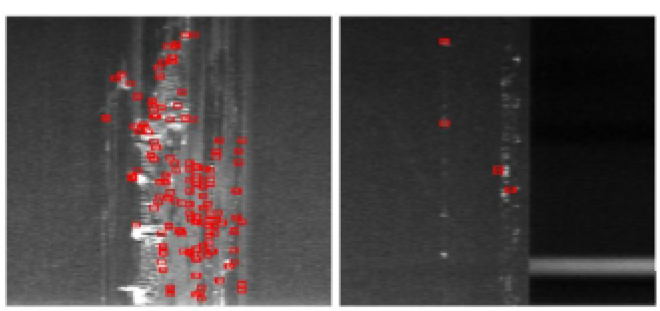


Figure 18 - Feature Points Detection on the Defected Regions

We realize that feature detection methods do not produce results with the accuracy needed for car parts and sheet metal defect detection. We propose an alternative method that involves changing the input sensor. Using a laser scanner we can have 2D profiles as visual input. This data is easier to read and implement in a machine learning environment. It also provides highly accurate data for part dimension and feature verification.

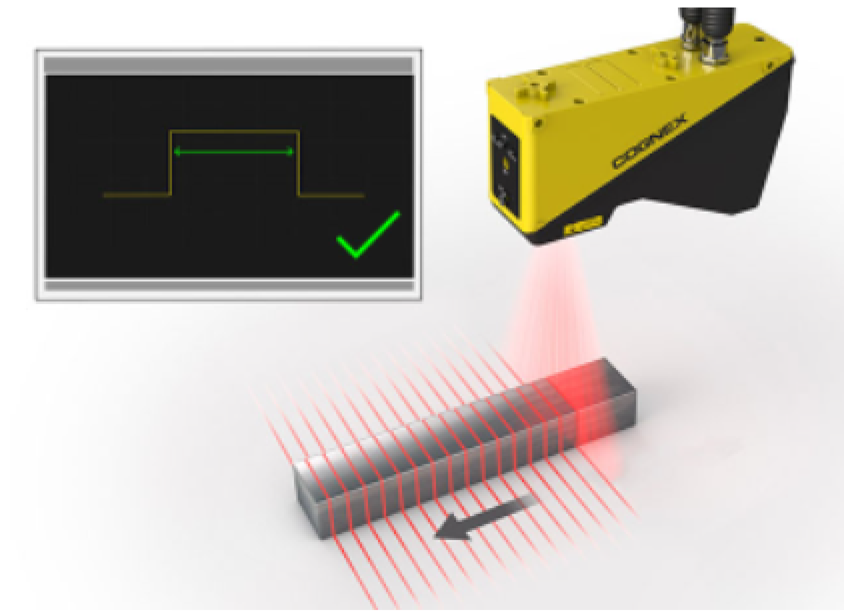


Figure 19 - Cognex In-Sight Laser Profiler

Surface Defect Detection

Surface defect detection algorithms provide a consistent evaluation of surface topography and form at localized regions and highlight defects including dents, scratches, peels etc. Through investigation, it is discovered that there is currently little literature review on machine learning methods in the field of surface defect detection for industrial products and that while some literature summarizes the problems and challenges in surface defect detection for industrial products, their solutions and directions are not systematic enough. Furthermore, there is yet no comprehensive collection of industrial product surface defect detection datasets available. To address the aforementioned issues, this study first describes the current state of research on industrial product surface defect identification using classical machine vision and deep learning methods.

- Traditional Surface Defect Detection: From the feature extraction level, this part classifies the typical industrial product surface defect detection approach based on machine vision. The different features are mainly divided into three categories: texture feature-based method, colour feature-based method, and shape feature-based method. The specific further chapter arrangement is shown in the figure below.

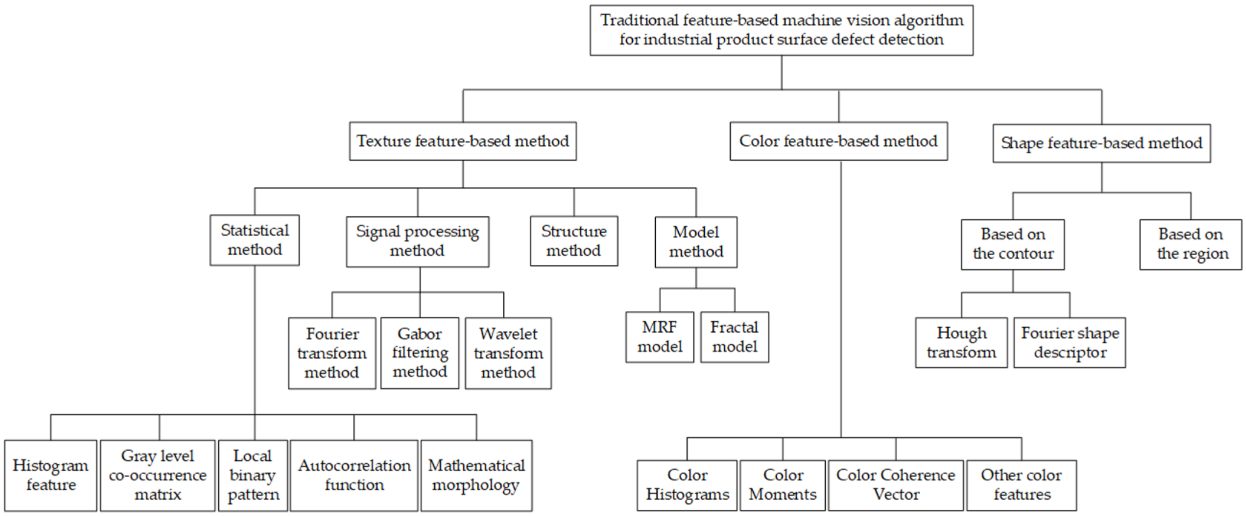


Figure 20 - Classification of Traditional Machine Vision Methods for Surface Defect Detection

a. Texture Feature-Based Method: Through the grey distribution of the pixels and their nearby spatial regions, the texture feature indicates the homogeneity phenomena in the image and can reflect the organization structure and arrangement qualities of the image surface.
b. Colour Feature-Based Method: The colour feature's computation amount is tiny, and it has low dependence on the image's size, direction, viewing angle, and other parameters. It's one of the most commonly utilized visual features in picture retrieval
c. Colour Histograms: The colour histogram is a global statistic that describes the proportion of distinct hues in an image; it ignores the spatial position of the colour and is unable to identify the objects in the image.
d. Colour Moments: The primary concept behind colour moments is that every colour distribution in a picture can be represented by its order moments. Because low-order moments contain most of the colour distribution information, merely the first-order moment (mean), second-order moment (variance), and third-order moment (offset) of the colour is usually sufficient to display the colour of the image surface distributed.
e. Color Coherence Vector: The colour coherence vector is an improved colour histogram algorithm; its main idea is that each colour cluster in the histogram is divided into two parts: aggregation and non-aggregation; in the process of image similarity comparison, the similarity is compared

separately, and then a similar value is obtained after a comprehensive trade-off.

f. Shape Feature-Based Method: The method that is based on shape efficiently uses the image's target of interest for retrieval. The contour-based technique is the most common among them. The contour-based method derives the image's shape parameters by describing the object's outer boundary characteristics; examples include the Hough transform and Fourier shape descriptor. The Hough transform connects the edge pixels to build the region's closed boundary using the image's global features, and its theoretical foundation is the duality of point to the line. [11]

Usage of Machine Learning and Deep Learning Techniques for Defect Detection

Deep learning is becoming increasingly popular in the field of defect detection because of its rapid progress. This section is based on the common classifications of deep learning: supervised method, unsupervised method, and weakly supervised method.

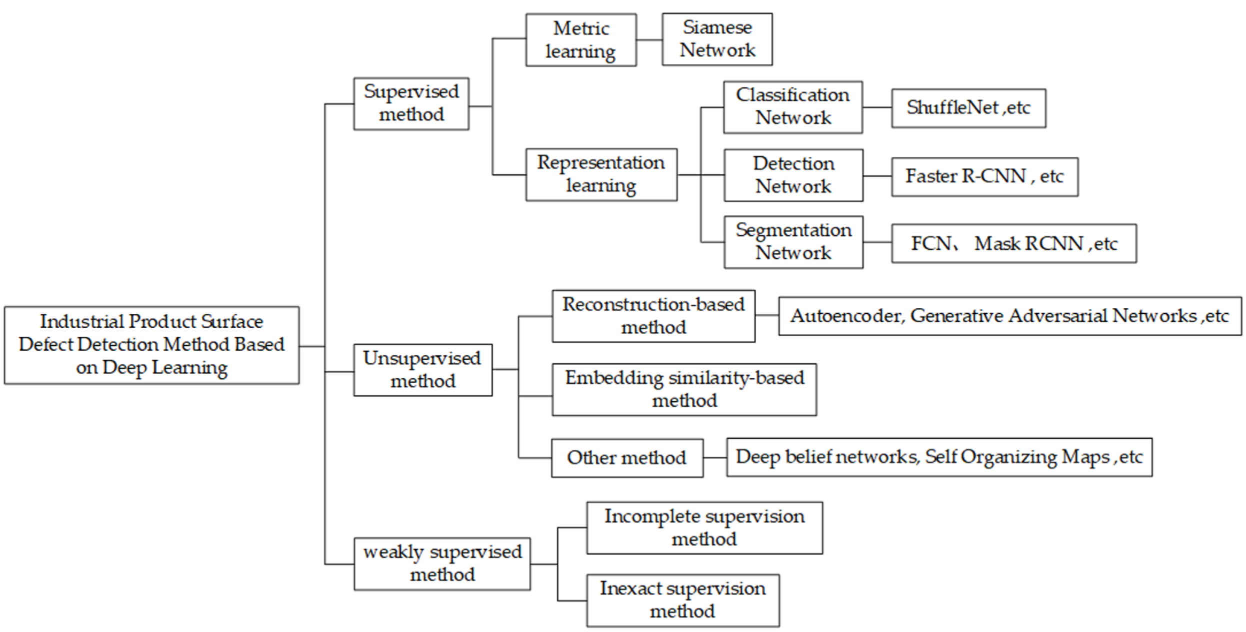


Figure 21 - Classification of Deep Learning Methods for Surface Defect detection

- Supervised Method: The training set and the test set are both required in the supervised technique, and the samples in the training set must be labelled, with the training set being used to determine the samples' intrinsic laws and then applying the laws in the test set. There are two types of supervised methods:

supervised methods based on metric learning and supervised methods based on representation learning. In the application of defect detection for car parts, this method will theoretically provide the most accurate predictions. But labelling the data that are defective is extremely difficult to obtain and hence can not be used. We propose to use a semi-supervised learning model that labels everything outside the boundary of normal samples (un-defected samples) to be anomalies/defects. Running our training model like this finally gives us enough information for a labelled dataset for defects to be produced which no we can use for supervised learning.

- Unsupervised Method: Some researchers have begun to investigate unsupervised approaches in reaction to the drawbacks of supervised methods. When the input training data consists solely of data information and no label information, the machine learns the pattern of these unlabeled data in order to extract some inherent properties and connections of the data and automatically classifies it. Then, when new data is met, it can use the previously learnt model to determine which model the new data belongs to (here, the model refers to the model composed of original data). This is an example of unsupervised learning.
- Weakly Supervised Method: Some researchers mix the features of supervised and unsupervised methods to create the weakly supervised technique. When compared to supervised and unsupervised approaches, the weakly supervised method performs better while avoiding greater markup costs. Incomplete supervision and incorrect supervision are two of the most widely utilized weak supervised approaches in the examination of industrial surface defects nowadays. Supervised detection contains both the defect-free and defective labelled samples in the training test. However, semi-supervised learning only contains the defect-free labelled dataset. (also known as the one-class classification method). This method is useful as it does not require a large number of defective samples. [18]

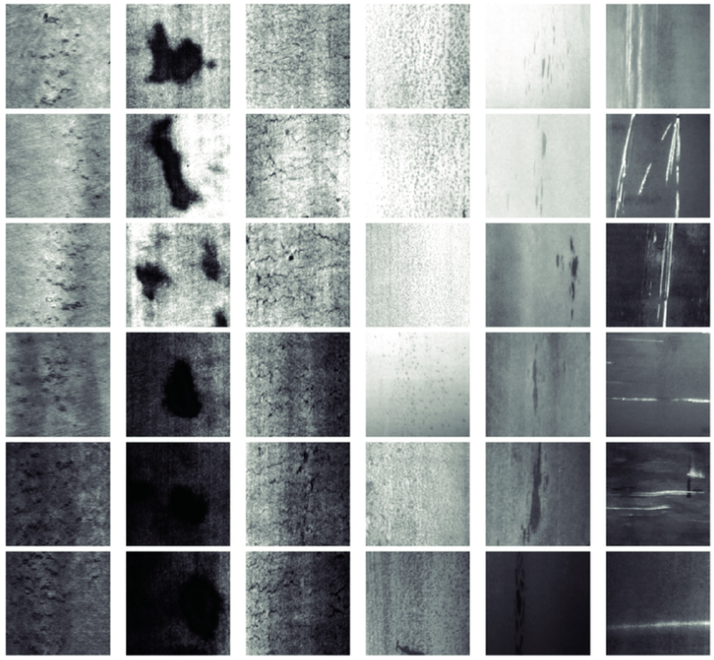


Figure 22 - Steel Sheet Metal surface defect detection using Deep learning.

12. Simulation

Be it any business, big or small building physical products or not, all of their development lifecycle processes start as an idea and then that idea is worked upon to be delivered as a value proposition. We create an accurate model for our processes, apply a lot of real-world constraints to it and run simulations on our models.

Why do we need simulation?

- The biggest benefit of simulation is that it saves a lot of time, effort and capital involved in the entire research and development process. We all know how the cost is usually the biggest bottleneck for most R & D projects. Simulation, more often than not, saves companies money to the tune of millions of dollars, so why wouldn't they use it?
- With the results obtained from the simulation, we can quickly go back to the drawing board and brainstorm to address the issues, make necessary changes and then go ahead with these changes
- We can keep making multiple iterations of the simulations until we are satisfied with the results and only then go ahead with production
- They also have the ability to increase or decrease the time factor hence helping us run an entire day's worth of simulation in a few minutes.

To help better understand our proposal we have made of Discrete Event Simulation of our proposal. The simulation is made using FlexSim, a Discrete Event Simulation software which helps create 3D objects of the scenarios and add flow logic to it so as to end up with highly accurate simulations of real-life scenarios.

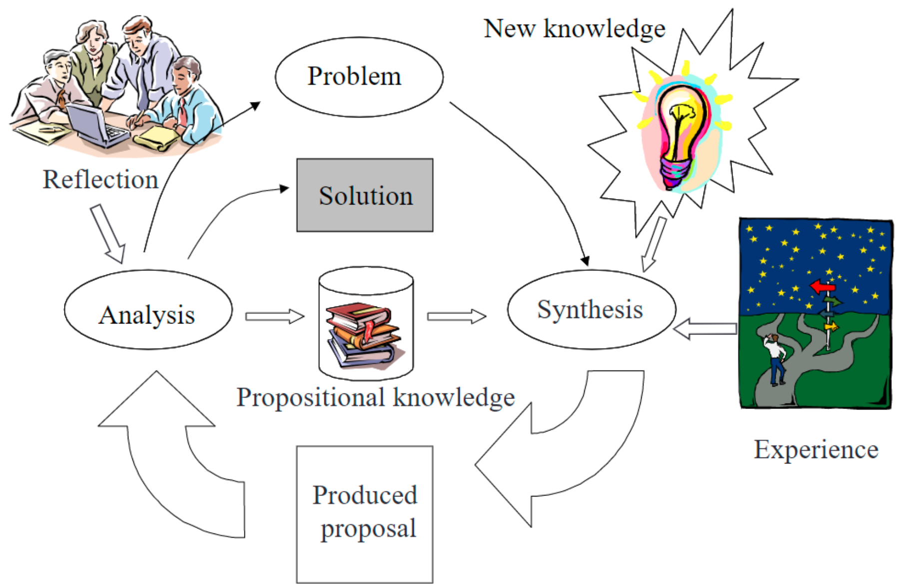


Figure 23 - The Problem-Solving Lifecycle

In the above-mentioned problem-solving lifecycle process, the simulations hold a place in the 'Analysis' section of the lifecycle. There are many ways of approaching the simulations. Either through process flow models or through 3D Models.

Approaches to simulation

- Process Flow Models - Models in which the processes are arranged in a sort of flow chart logic. Good for assessing large simulations
- 3D Models - As the name suggests it refers to reproducing each part of your simulation as 3D models. It is easy to visualise and understand. Especially when you are showing it to stakeholders who may not be familiar with internal logic or shorthands.

Both use some sort of an assessment factor. This factor is usually the time taken for the process. But it could be other things such as cost, number of outputs, etc. This factor can be anything you want it to be.

Before we head into the simulations, a few keywords related to the simulation need to be defined. 3D simulation is made up of objects

- Source - Sources create flow items. In our case, it represents the arrival of parts at the inspection station

- Queue - Queues store flow items until they can be sent to another object, In our case, it will act as a buffer for the storage of the parts that arrive
- Processor - Processors process flow items, which are typically simulated as a time delay. Here the human being is the processor in human inspection and in the case of vision systems, it is the camera arrays.
- Sink - Sinks remove flow items from the simulation model. In our model, it represents the parts leaving the system

Now that we know our definitions, we can just add relevant objects from the software's object library and create our scene.

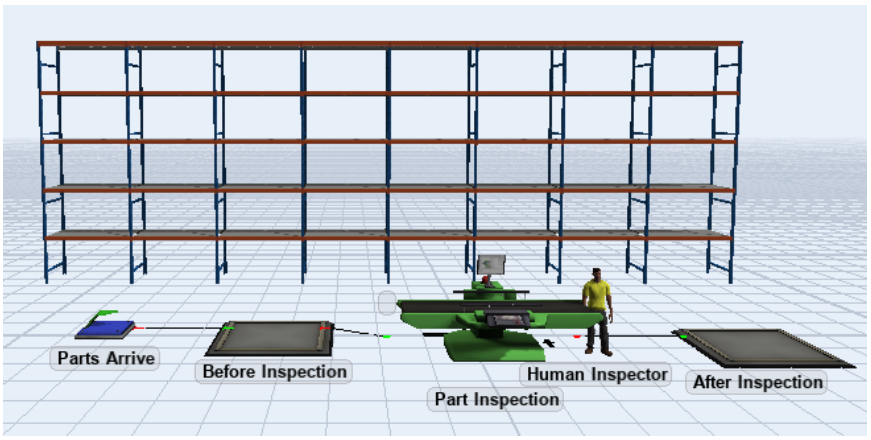


Figure 24 - Simulation model with Human inspection

Here the parts arrive is the source which represents parts entering the system for inspection. Before the inspection, the parts are stored in the queue. The parts inspection and human inspector are part of the processor. These entities are the primary place which performs the inspection of the part. Now after inspection, the parts are stored in another queue which will then leave the system through a sink (not shown in the image) which represents the parts going forward to the next operation be it assembly or painting etc.

The image shown above, figure no 14, is the model for the scenario where humans will be doing the inspection. Since we are proposing a solution where the inspection is done using a camera array, we created a new model with the relevant entities as can be seen in the image below in figure 15.

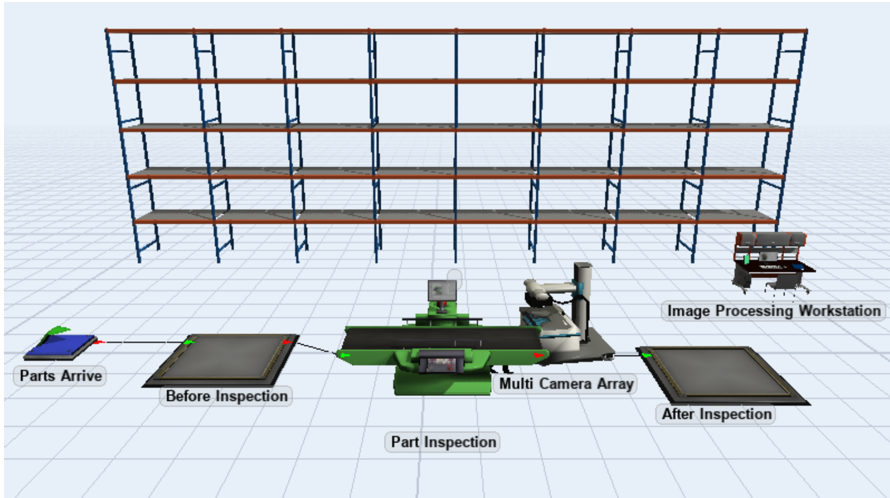


Figure 25 - Simulation model with vision-based inspection

In the second case, we can see that a multi-camera array has replaced the human inspector and there is an image processing workstation that will provide the computational help needed for the inspection. In this simulation model too, similar to the previous one, the parts arrive, store in the queue until inspection, the inspection is done using the camera system and the exits after inspection.

Two different models were created to analyse the output in each case and make informed decisions based on numbers as to which method is more efficient. The criteria for assessment in each case was the number of parts inspected per shift. The human inspector can assess each part in between 10 to 15 seconds. This information has been gathered by timing the human inspection process from the videos of industries. Whereas, based on our understanding of how the image processing operations work, we estimate the vision-based system to take between 5 to 7 seconds to inspect each part. Now the benefit of simulation is that we can speed up the time factor and run the simulation for any time period of choice. We run both our simulation models for an entire shift of 8 hours. And these were our results.

- Human Inspection: 2299 parts (inspection rate of 10 to 15 seconds per part)
- Vision-based Inspection: 4797 parts (inspection rate of 5 to 7 seconds per part)
- The camera array system is just over 2 times as efficient as a human for the same amount of time.

The videos for the simulation can be accessed here
Video for the Human simulation model: Available here
Video for the Vision-based simulation model: Available here

13. Discussions & Conclusions

As we have seen from the results of the simulation, the Vision-based simulation produces better results in terms of efficiency of parts inspection. This improvement in efficiency plays a huge role in the industry as it helps speed up the automotive manufacturing process. This process also plays an important role in reducing the errors in judgement due to human inspection which may cause inaccurate clarification of the part as either defective or not. In this way, we can reduce our costs by having to recycle only those parts which are truly defective. On the other hand, we also reduce our risk of passing off a defective part as a perfect part.

The automotive industry, among others, heavily relies on good word-of-mouth marketing. If the customers who buy their vehicles are satisfied with the quality they are offered, they will go out of their way to recommend them to their friends and family. Word of mouth marketing also helps manufacturers tweak their offerings to cash in on the good credit they have built in the public eye. [4]

We conclude with the fact that getting two major benefits (improved inspection efficiency and accuracy) from a single act (switching from manual inspection to vision-based inspection) will go a long way in helping companies deliver good products and at the same time emerge as a reliable player in the automotive sector.

14. Smart Manufacturing Recommendations

All the data collected from the sensors can be stored in a centralized repository thus reducing the need for R&D in each manufacturing plant. This kind of decentralized system for information sharing can help create its own ecosystem for Smart Manufacturing.

15. Acknowledgements

"I would like to express my gratitude to my fellow classmate and friend, Pradipkumar Kathiriya for giving me great insights toward this project. Pradip was a former employee of Maruti Suzuki, Ahmedabad, India. He was working on a similar project back there and his team was working on solving the process of inaccuracies which were caused due to lapses in the manual inspection.

With his permission, I share the following image of a car part which has been inspected by the use of a vision-based system. We can see that the algorithm was robust enough to zero down on the defect and classify it as such. The images shared here are sensitive information belonging to the company. Sharing of the following images without explicit consent is prohibited" - Hemanth Joseph Raj

Figure 26 - Defect detected in a car part

Figure 27 - Defect detected in a car part

16. References

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11. Yajun Chen, Yuanyuan Ding, Fan Zhao, Erhu Zhang, Zhangnan Wu and Linhao Shao, (2021), “Surface Defect Detection Methods for Industrial Products: A Review”

17. Resources

1. Lecture Slides - Professor Dr Mahesh Mani
2. Text Book: The Automotive Body Manufacturing Systems and Processes by Mohammed A.Omar (by Wiley publications)
3. FlexSim 3D Discrete Event Simulation Software - student edition
4. “Automobile Manufacturing Process” by TOYOTA Pvt.Ltd
5. “How to choose an automatic stamping production line" from HARSLE
6. “Automotive OEM Process” by Gekatex Group
7. “Press Machines and Metal Stamping” from machinemfg.com
8. “Metal Stamping” from American Industrial Company
9. “Sheet Metal Forming” from MEVEPA Italy company
10. “Press Shop Goes Digital, Improving Quality” by Metrology.news
11. “Welding Services” by Technox machine and Manufacturing Inc.
12. “6 Lessons We Can Learn from Lean Manufacturing” from CIO.com
13. Cognex 2D Laser profiler https://www.cognex.com/products/machine-vision/3d-machine-vision-systems/in-sight-laser-profile