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Design Failure Modes and Effects Analysis (DFMEA) of Self Propelled Onion Harvester (TIFAN Vehicle)

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Abstract: ***The SAEI-OHB (Society of Automotive ENGINEERING India) organizes TIFAN(Technology Innovation Forum for Agricultural Nurturing) competition, challenges teams of undergraduate engineering students to conceive, design, fabricate, develop and compete with self-propelled farm machinery, in an event with field demonstration. This competition is designed to solve problem arising at farm. Students designed and fabricated the overall self-propelled onion harvester. While designing the harvester, most important requirement is design strong and safe harvester, it involves identifying and analysing various failure modes in initial stage of design. And the most effective method of identifying and analysing failure mode is DFMEA (Design Failure Mode Effect Analysis). DFMEA is Extension of FMEA and is done in initial stage of design. The present project work is carried out to develop Failure Mode Effect Analysis for Self Propelled onion harvester. Two main pillars contributing to performance of Onion harvester are servicing and maintenance. Our area of interest is to analyse failure mode, cause of failure and recommend action to prevent failure. Failure mode effect analysis will give real time causes and effect of failure. Control system such as preventive action and detection is done to prevent failure. In this FMEA is method used to identify different failure mode of different part of harvester or machinery like vehicle, engine, etc., it also identify failure causes, its effect and method to prevent it. Risk priority number technique of FMEA is employed to analyse which part has more possibility to fail and necessary to change or require more attention.***

Keywords: TIFAN, Self-propelled, Design Failure Mode and Effect Analysis (DFMEA), Risk Priority Number (RPN), Severity

I. INTRODUCTION

The main objective of agriculture or farming is increase crop production and productivity which will strengthen the economic status of farmer and fulfil their life-style. It means growing of crops and economic growth of farmers and labours is main aim of agriculture. However labour shortage has display serious challenge to crop procurement and is threatening to leave a long lasting impact on agriculture because it can delay the harvest of crops and is delaying the planting of next crops. This problem affects the fiscal growth of farmers as well as development of their farmlands and family. That's why effective, efficient, cheap, effective, and productive techniques are required to strengthen the farming community. Therefore, the main focus was to develop a machine which addresses labour problem faced by farmers. This report tries to summarize steps taken in finalizing the design. The requirement of chassis, digging, and conveying, windrowing, transmission, hydraulic and steering system are considered here. Every component of this harvester was carefully engineered, analysed and tested. Objective of the design was to satisfy the functions while meeting the SAE's TIFAN rules and regulations ease of manufacturing, cost, weight (dynamic behaviour) and overall aesthetics and performance. We analysed a machine which gives good performance in terms of productivity, coverage, fuel economy, operator comfort, handling, operating speed and safety of operator. The Paper is a cumulative effort towards explaining the FMEA to the reader. Self-propelled onion harvester designed to dig onion, convey the onion from digging system to the windrowing system and also separate the soil while conveying onion and then windrow the onion to the ground for further collection. The design of the vehicle is monotonous activity and it is done according to various engineering and reverse engineering processes subjected to availability, cost and design factor. We design self-propelled onion harvester considering various aspects and also done modelling on different CAD software's namely CATIA, SOLIDWORK and analyse them using ANSYS software. Afterward depending upon ANSYS analysis outcome, model was rectified, redesign, tested again and finalise the design. Students designed and fabricated the self-propelled onion harvester. While fabricating the harvester, design is most important stage for development of harvester. Being a self-propelled farm machinery and less powered harvester, strong and safe design is necessary condition. Different part of harvester can fail indifferent way, leading to compromise safety.

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Therefore, a complete and organize study of the machinery (vehicle) in the design stage is essential. As the guidelines given in TIFAN rulebook, this complete and organize failure analysis can be carried out by approved reliability analysis method called Failure Mode Effect Analysis. Failure Mode and Effects Analysis (FMEA) is method designed to:

1) Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process [4].
2) Assess the risk associated with the identified failure modes, effects, and causes, and prioritize issues for corrective action [4].
3) Identify and carry out corrective actions to address the most serious concerns [4].

An effective application of FMEA in product design stage is employed during this project. Risk priority number methodology of FMEA is used to analyse which part has more possibility to fail and necessary to change or require more attention, which is employed during this project.

II. LITERATURE REVIEW

ABS book et al. [1] An FMEA is a design and engineering tool which analyses potential failure modes within a system to determine the impact of those failures. Rob keefer PhD et al. [2] originally developed to understand reliability of manufacturing systems and manufactured components to identify failure modes and their causes and effects. Jigar Doshi et al. [3] Failure Mode and Effects Analysis (FMEA) is a standard tool used to recognize potential failures and associated effects on processes and products, thus constant development in quality can be achieved by nullifying them. Carl S. Carlson et al. [4] FMEA is a technique which enables: a) Recognize and fully acknowledge potential failure modes and their causes, and therefore the effects of failure on the system or costumer, for a given product or process. b) Assess the risk related with the known failure modes, effects and hence causes, and prioritize problems for rectification. c) Determine and perform recommended actions to deal with foremost critical concerns.
FLORINA et al.[5] The FMEA analysis is proposed to reduce errors at begin of series production and shorten the event length, increased product reliability and safety in operation, and creation a cognitive content in an industry. G. Sandeep kumaret al.[6]A successful FMEA activity helps to recognize potential failure modes of component on the basis of past knowledge with similar products or processes, letting the team to design the failures out of the system with the less effort and resources, hence cutting development time and cost. Rishav Kumaret al. [7] FMEA is an effective method used for recognising the probable failures and reducing their effects. Risk Priority Number (RPN) methodology is used to find the crucial parts which are prone to failure and requires extra attention. Design advancement could be done on the basis of the FMEA work table, particular for most crucial failure mode having high preventive issues. Rahul Shrivastava et al. [8] FMEA is a step by step approach for recognizing all probable failures in a design, a manufacturing or assembly process or a product or service. Using this tool we could recognize the crucial part of the system and causes of their failures. It enables to know RPN and bring down the failure and improving reliability of the system. A.K. Josiahet al. [9] FMEA is an elementary reliability analysis technique used in industrial systems with several interacting components for failure modes recognition and prioritization with the eventual goal of eliminating the failure modes causal factors. Baishakhi Behera et al. [10] DFMEA is an enlargement of mostly used FMEA tool, which is perform in the design stage. DFMEA enables to predict and analyse different failure modes of a vehicle, its cause & effects and to indicate preventions. FMEA handbook by Ford et al. [11] FMEAs determines potential and confirms Critical and vital Characteristics to be recognized by design changes, process changes, or in Process Control Plans. Jawagar Shrehari J1et al. [12] FMEA play a great role in assessing the failure modes, effects and its causes and help the users in developing the system or rectify it.

III. FAILURE MODES AND EFFECTS ANALYSIS

The true history of FMEA begins by the U.S. Military in year of 1949, by the introduction of Military procedure document of (MIL-p)-1629, “Procedure for performing a failure mode effect and critical analysis”, the key reason behind FMEA is to rank the failures, “On the basis of their effect on success of mission and safety.” It is further used in Apollo program also. FMEA is dominant tool in Design for Reliability. FMEAs are unit supposed to anticipate potential risk and develop action which will scale back risk to the suitable level.
FMEA is a systematized, dynamic technique for estimating a process to point out failure mode and to find the similar effect of failure, to find the parts of the process that are more required to change.

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FMEA is correcting and finding failure modes before the product gets to the client. An FMEA is associated with an analysis done by team of subject matter specialist that completely analyses manufacturing processes or product designs, before in the product development process.

An FMEA should be the lead to the development of a all set of actions which will scale back risk related to the system, subsystem, and parts or manufacturing/assembly process to an acceptable level.

The main objective of an FMEA is to improve the design.

There are many other objectives for doing FMEAs, such as:

1) Identify and prevent safety hazards [4].
2) Minimize loss of product performance or performance degradation [4].
3) Improve test and verification plans (in the case of System or Design FMEAs) [4].
4) Improve Process Control Plans (in the case of Process FMEAs) [4].
5) Consider changes to the product design or manufacturing process [4].
6) Identify significant product or process characteristics [4].
7) Develop Preventive Maintenance plans for in - service machinery and equipment [4].
8) Develop online diagnostic techniques [4].

IV. METHODOLOGY

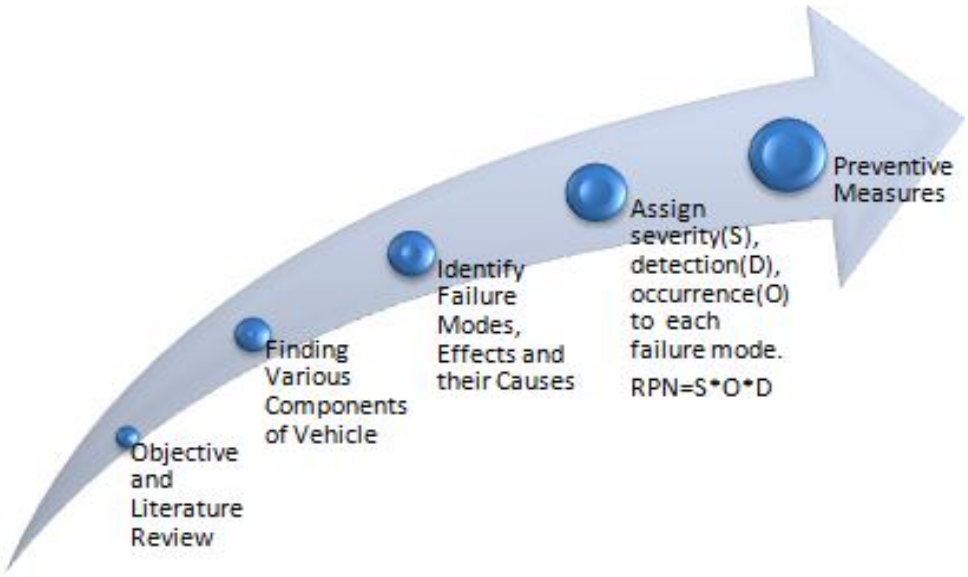


Figure 1

V. SEVERITY, OCCURRENCE AND DETECTION

"Severity" is a ranking number associated with the most serious effect for a given failure mode, based on the criteria from severity scale [4]. It is a relative ranking within the scope of the specific FMEA and is determined without regard to the likelihood of occurrence or detection [4].

"Occurrence" is a ranking number associated with the likelihood that the failure mode and its associated cause will be present in the item being analyzed [4]. For System and Design FMEAs, the occurrence ranking considers the likelihood of occurrence during the design life of the product [4]. For Process FMEAs the occurrence ranking considers the likelihood of occurrence during production [4]. The occurrence ranking has a relative meaning rather than an absolute value and is determined without regard to the severity or likelihood of detection [4].

"Detection" is a ranking number associated with the best control from the list of detection-type controls, based on the criteria from the detection scale [4]. Detection is a relative ranking within the scope of the specific FMEA and is determined without regard to the severity or likelihood of occurrence [4].

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Table-1: Severity Evaluation and Rating Criteria

Sr. No.	SEVERITY CLASSIFICATION	DESCRIPTION	SEVERITY RATING
1	Extremely Hazardous	Failure happens erratically typically by surprise. It doesn't show compliance with government laws. Safety of the driver's/ Machine operators is compromised. Often the vehicle becomes inoperable.	10
2	Hazard occurs with warning/Very Dangerous	Failure is venturous and really dangerous, however happens with warning. It risks human life/operator and end up in harm to vehicle/machine on the far side repair. . It doesn't show compliance with government laws.	9
3	Very High	Machine/Vehicle/Item goes out of action. This considers major repair. Here safety isn't compromise and failure is in compliance with government and safety laws.	8
4	High	Reduced performance still Machine is operable. However can be repaired but has some difficulty.	7
5	Moderate	Primary function of machine intact. However comfort is compromised. Failure occurred in a part of the system however are often fixed.	6
6	Low	Machine/system can be operated but at low comfort hence affecting performance. It leads considerable performance loss for repair and rework.	5
7	Very Low	Little modifications can tackle small failures. No essential loss to the system. Fitting and Finishing failures area concerned here.	4
8	Minor	It causes very little annoyance however there is no performance loss. Many times minor rework can fix it.	3
9	Very Minor	Vehicle/system is operable with minimum problem. Failure isn't ascertained easily. Repair and rework might not be required.	2
10	None	No detectable result of the failure and doesn't have an effect on the performance of the system.	1

Table-2: Probability of occurrence

Sr. No.	PROBABILITY OF OCCURRENCE	DEFINITION Every X component fails (1:X)	RATING
1.	Extremely High	1:3	10
2.	High: Similar processes have often failed	1:6	9
3.	High: repeated failures	1:9	8
4.	High: frequent failures	1:50	7
5.	Moderately High	1:150	6
6.	Moderate	1:800	5
7.	Moderately Low	1:4500	4
8.	Low	1:30000	3
9.	Very Low	1:150000	2
10.	Remote	1:1.5million	1

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Table-3: Probability of detection of failure mode

Sr. No.	DETECTION	DEFINITION	RATING
1.	Almost no detection	Almost negligible chances of detection by control	10
2.	Very Remote	Very few chances of detection by controls	9
3.	Remote	Poor chance of detection by controls	8
4.	Very Low	Very less chance of detection by controls	7
5.	Low	Detection may be possible by control	6
6.	Moderate	Moderate chance of detection by control	5
7.	Moderately High	Good chance of detection by controls	4
8.	High	Certainly detection by control	3
9.	Very High	Almost certainty of detection by control	2
10.	Almost certain	Certainty of detection by controls	1

VI. DFMEA IMPLEMENTATION

DFMEA is performed on 20 crucial components of the Self-Propelled onion harvester. The DFMEA is performed on the components which include braking system, Engine, Clutch, Gearbox Assembly, PTO shaft, Steering wheel and steering column, Steering gear assembly, Tie Rod(Drag link), Drop arm (Pitman arm), Stub axle, axle, Tire, Rim, Frame, Conveyor Chain, Conveyor sprocket, Conveyor shaft, Steel rods of conveyor, vehicle electrical components and digging blade. The detailed DFMEA process is summarized in following table.

Table-4. DFME of Self Propelled Onion Harvester

Sr. NO.	ITEM	FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL EFFECT OF FAILURE	POTENTIAL CAUSE OF FAILURE	SAVERITY	OCCURANCE	DETECTION	RPN	RECOMMENDED ACTIONS
1	Braking System	Provide required amount of friction in-between brake shoes and drum to stop the vehicle under all operating condition	1) Brake pedal travel too long	End User: vehicle does not slow down within required distance when the brake is applied resulting in accident	1) worn lining; leaking brake system	9	2	3	54	Select components with higher FOS; Assembly should be done properly; Careful testing.
			2) Brake pedal spongy		2) Air in brake system	9	2	2	36	
			3) Brake malfunctioning(after bleeding of brake)		3)master cylinder valve defective	9	3	3	81	
			4) Brake pedal fail to regain original position		4) Leakage in brake lines in master or wheel cylinder	9	3	3	81	
			5) Brake heating while driving		5) When master cylinder piston is in released position, the compensating port connecting reservoir and master cylinder is not open ; due to aging brake shoe return springs too weak	9	3	3	81	

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			6) No or low braking performance, hard pedal		6) Contamination in brake lining due to oil/water; wrong brake linings; leakage in brake system ;defective seals in master cylinder	9	2	3	54	
			7) Brakes make noise while braking		7) Brake drum not round; dirt contamination of linings; metal shoe contacting drum	9	2	3	54	
			8) Brake dose not release		8)master cylinder piston frozen; shoe return springs weak or broken; wheel cylinder piston(s) frozen	9	2	2	36	
			9) Brake pedal vibration		9) wheel cylinder vibrations produce waves in brake fluid; excessive wheel bearing looseness; or drum not round	9	3	3	81	
			10) Brake pedal break		10)selection of Incorrect material; incorrect geometry design	9	4	2	72	
2	Engine	prime mover	1) Engine components damage	system will become inoperable	1) wear out of cylinder surface, piston ring	8	1	7	56	Maintenance should be done after regular interval
			2) power loss	System will operable but at reduced performance	2) Improper Air-Fuel ratio due to unconditional environment	7	3	4	84	position of engine should be set so that it can access free air, also standardize and filtered fuel is used
			3) High Emission		3) improper lubricating oil is used; improper fuel is used		3	4	84	Oil should be changed after regular interval
			4)Leakage in fuel tank	Engine fuel fire; poor engine performance and fuel economy	4)malfunctioning of fuel tank and improper handling	10	2	3	60	proper handling of components
3	clutch	transits power from engine to gear box	1) mechanical failure	no power transmission	1)slippage of clutch bolt	8	3	4	96	selecting clutch bolt and attachment as suitable for given load.

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4	gearbox assembly	power transmission	1) mechanical failure	vibration is produced	1) Tooth breakage, wear out; improper meshing; bearing failure	6	2	8	96	Checking the engagement of tooth and also condition of tooths
			2)Jamming of gear shifter	vehicle inoperative; sometimes control lost	2)Improper lubrication	8	2	3	48	Proper lubrication should be done
5	PTO shaft	power transmission to conveyor	1)Vibration	System will operable but at reduced performance	1) Misalignment in assembly	5	3	2	30	Alignment should be proper
			2)mechanical failure		2) breakage of splines		2	6	60	verification of desired specification
			3)Breakage or bending	power to conveyor is cut off	3) Overloading	8	2	2	32	Use higher FOS
6	Steering wheel and steering column	To produce necessary force to turn steering gear	1)Breakage	Affect the safety of vehicle and individuals	1)Excess load applied by driver; incorrect material	9	2	2	36	Verification of desired specification and testing
			2)Bending failure; Torsional failure; Buckling failure	Steering Mechanism fails	2)Breakage leading to steering column failure; Excess load applied by driver	9	2	2	36	
			3)Excess vibration	Improper Stability	3)Rough terrain travel; gear teeth, joints worn out	6	6	1	36	
7	Steering gear assembly	To multiply steering effort	1) mechanical failure	Affect the safety of driver and others	1)Tooth breakage, wear out	5	2	6	60	Verification of desired specification and testing
			2) Corrosion	Steering Mechanism fails	2)Improper lubrication	8	3	3	72	Proper lubrication should be done
8	Drag link(Tie Rod)	To vary length for correct steering; Connection between steering linkage and steering column	1)Metal fatigue; cracking	chance for collision	1)Rough terrain; excessive loading during steering	9	2	3	54	Verification of desired specification and testing
			2)Corrosion	vehicle performance is affected	2)Moisture content	4	6	1	24	
			3)variation in tie rod alignment; steering ratio varies	Improper Stability; tire wear	3)Improper manufacturing process; misalignment; loosening of bolts	6	3	3	54	Verification of desired specification and testing

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9	Drop Arm(Pitman arm)	Transmitting Turning Force From Steering Gear to drag link	1)Metal fatigue; cracking	chance for collision	1)Rough terrain; excessive loading during steering	9	2	3	54	Verification of desired specification and testing
			2)Corrosion	vehicle performance is affected	2)Moisture content	4	6	1	24	
			3)variation in tie rod alignment; steering ratio varies	Improper Stability; tire wear	3)Improper manufacturing process; misalignment; loosening of bolts	6	3	3	54	Verification of desired specification and testing
10	Stub Axle	Capable angular movement about king pin for steering	1)Metal fatigue; cracking	chance for collision	1)Rough terrain; excessive loading during steering	9	2	3	54	Verification of desired specification and testing
			2)Corrosion	vehicle performance is affected	2)Moisture content	4	6	1	24	
			3)variation in tie rod alignment; steering ratio varies	Improper Stability; tire wear	3)Improper manufacturing process; misalignment; loosening of bolts	6	3	3	54	Verification of desired specification and testing
11	Axle	To bear weight of vehicle	1)Bending; Breaking	lead to serious accident	1)overloading; Inadequate result from 3D designing; not proper machining	8	3	3	72	Verification of desired specification and testing
			2)corrosion		2)improper machining	2	5	1	10	
12	Tire	To support load of the vehicle, absorb shocks, transmit tractive force, torque and also braking forces to the road surface. maintain and change the direction of vehicle	1)sidewall failure	may loose control of vehicle	1)Puncture, Excess inflation; Improper mounting	7	6	1	42	Verification of desired specification and testing
			2)wear and tear	affect vehicle speed and smooth working	3)Low quality tires	5	5	2	50	
13	Rim	supporting and sealing the tire to the wheel.	1)Brittle and ductile fracture	Vehicle become inoperable	1)On road damage; Large radial and tangential stress	7	2	2	28	Verification of desired specification and testing
			2)Fretting fatigue		2)On road damage; Large radial and tangential stress	7	2	2	28	
14	Frame	supporting and bearing the load of the vehicle body	1)Partial Breaking or bending of frame	Risk to safety of driver	1)Stress exceeds yield stress of material; Vertical and shear loading, when driving over an uneven surface	7	3	3	63	Verification of desired specification and testing
			2)Torsional failure	Overall damage to frame	2)Stress exceeds shear stress of material; Accidents or Excess loading	8	3	3	72	
		providing the space and mounting location for various components of vehicle	3)Broken welds	Frame breaks and create risk to safety of driver	3)Inertial stresses due to acceleration and braking; improper welding	6	3	3	54	

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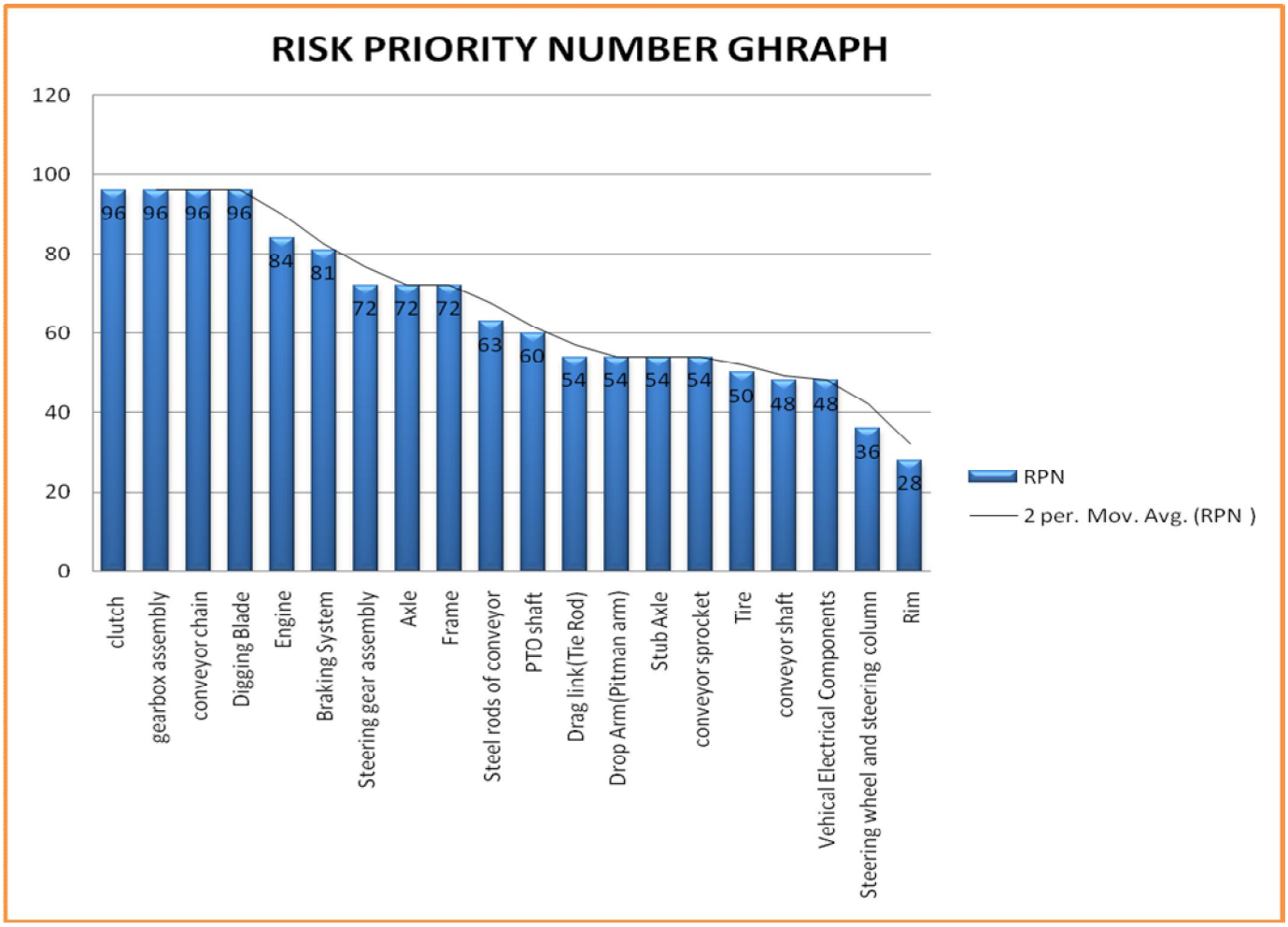
15	conveyor chain	To transmit onion	1)Chain breakage	complete failure to achieve main purpose of vehicle	1)Material strength is not enough	8	3	3	72	Verification of desired specification and testing
			2)Link separates from rivet		2)riveting is not properly done	8	3	4	96	
			3)Chain slip out from sprocket		3)Required alignment of chains is not done properly; loosening of chain after some interval of time after usage.	8	3	4	96	
					4)Necessary oiling is not done					Frequently maintenance is required
16	conveyor sprocket	Transmit power	1.Teeth break	working stop, conveyor may damage	1)Overloading of material over conveyor	5	2	5	50	verification of desired specifications
			2.rusting of sprocket	More power loss while transmission	2)Proper maintenance is not done	4	5	2	40	
			3.Key between sprocket and shaft fail	whole system brake	3)key strength is not enough; manufacturing is not proper; improper assembly	6	3	3	54	
17	conveyor shaft	Transmit power	1)Bending failure	conveyor working stops	1)Overloading of material over conveyor	7	2	3	42	verification of desired specifications
			2)Torsional failure		2)failure of bearings	8	2	3	48	
18	Steel rods of conveyor	Transmit Material	1)Bending failure	disturbs conveyor working	1)Overloading	3	3	7	63	verification of desired specifications
			2)Welding failure		2)improper welding	3	3	3	27	
19	Vehicle Electrical Components	Providing light, supply to emergency stop switch	1)Electrical failure	Electrical contact can endangers drives safety	1)Water damage/ electrical failure	8	2	3	48	Safe wiring and proper insulation should be made
20	Digging Blade	To dig onions with soil mass, lifting it and transferring it to conveyor	1)Breaking failure or cracking failure	Afflict functional capability	1)Stress exceeds yield stress of material	8	3	3	72	verification of desired specifications
			2)corrosion		2)Proper maintenance is not done; coating is not done	1	5	2	10	
			3)Bending failure		3)Stress exceeds yield stress of material	7	3	3	63	
			4)failure at mounting bolts; loosening of blade		4)Incorrect apply of torque for mounting	8	4	3	96	

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VII.PRIORITY GRAPH

After completion of DFMEA, the modes of failures from respective components are prioritized as per their Risk Priority Number in a Risk priority Graph (max.RPN value for component). Preventive actions are suggested considering the severity of component's RPN. The RPN graph is demonstrated as follow:



Graph 1. Risk Priority Graph for All system

VIII. DFMEA REPORT ANALYSIS/CONCLUSIONS

A. In this paper the FMEA technique is applied on student competition (TIFAN) where FMEA play a great role in determining the failure modes, effects and causes and help the client in developing the system or modify it.

B. A full-fledged FMEA was carried out on self-propelled onion harvester machine. For calculating the RPN of each component of machine, various parameters such as severity, likelihood of occurrence and detection were clearly described. From above analysis, component having high RPN (i.e. critical components) requires more attention so that preventive maintenance can be successful. Afterward, components prioritized according to its failure mode in the graph.

C. Components are prioritized on the basis of their failure mode in the graph 1, we found Clutch, Gearbox assembly, Conveyor chain, Digging blade, Engine were in top five most crucial components on the basis of their failure risk respectively. They indicate that they are very crucial to the quality of functioning of Onion harvester. Prevention techniques were listed out in details and also appropriate actions regarding these components and also for other components of the Onion harvester.

D. Afterwards recommended actions were taken regarding to their risk priority number, which helps in boosting life of parts as well as whole vehicle and thus increases reliability of product.

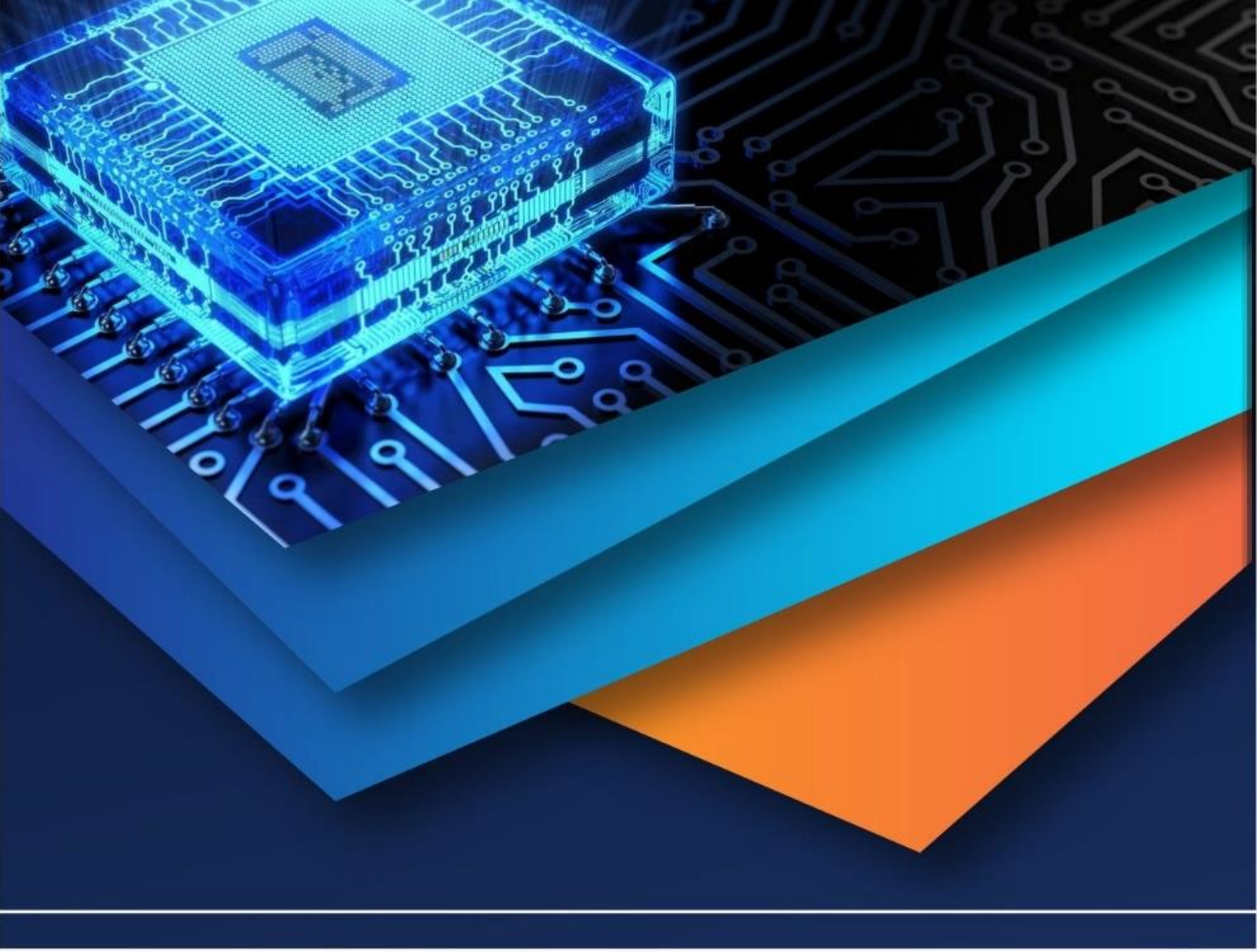
E. This project developed a model for machine (system) failure modes and effects evaluation that can be utilize in other similar set-ups with many interacting sub-systems for failure modes analysis.

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