

DESIGN FAILURE MODES AND EFFECTS ANALYSIS OF AN ELECTRIC KART

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Abstract

Ecokart is an all India level competition organised by (Viridescent Educational Services) in which an electric-kart is designed and fabricated by undergraduate engineering students. An electric kart is a small, four wheeled, open vehicle but unlike a go-kart which is powered by an internal combustion engine, electric kart is run by a motor which is powered by battery. Right from design considerations, the fabrication is to be done by modifying and assembling various components. DFMEA (Design Failure Mode and Effects Analysis) is branch of FMEA (Failure Mode and Effects Analysis) which is a quality management tool that identifies the critical components of a product followed by investigating different failure modes and their subsequent effects on the whole product. This paper implements DFMEA technique on an electric-kart by identifying various failure modes and their effects on the kart. RPN (Risk Priority Technique) is a famous sub tool of it which is used in this paper in order to find the components that are more susceptible to the failure and demands more attention. Preventive measures to reduce the chances of failure are also given in the paper.

Keywords: Risk Priority Number (RPN), Severity Ranking, Ecokart, Likelihood of Detection, Likelihood of occurrence.

1. INTRODUCTION

Karts are small, open and four wheel vehicles. Kart racing became famous in USA in late 1950s [1]. Ecokart [2] is a national level competition in India that focuses on designing and fabricating a compact electric kart i.e., the source of power for the vehicle is supplied by a motor, run by the battery. The basic difference between a go-kart [3] & electric-kart is the source of power, where a go-kart is run by an internal combustion engine, the electric kart is powered by the battery run motor. As the environment is polluted by the petrol run vehicles, there is a vital need to find alternatives and an electric kart is one of the best possible alternatives. Owing to the go-green concept of Ecokart, this competition is fast gaining its popularity. This competition involves the designing of the body of the kart in designing software. It consists designing of the frame whose various parts are lower frame side member (LFS), rear roll hoop (RRH), frontal lateral cross member (FLC), fore af bracing (FAB), side impact members (SIM), lateral diagonal bracing (LDB), under seat member (USM) [4, Fig.1], followed by the assembly of steering, braking systems, wheels and tires and the seat. The designing considerations like compactness, lightweight, durability and driver safety, load carrying capacity of chassis are kept in mind. Static and dynamic impact load testing are to be done in the designing software to make it feasible. Followed by designing, the fabrication process comes. Rectangular/circular tubes are to be used for the primary and secondary members of the frame. Generally, karts are smaller than cars so the subassemblies like braking system, steering systems, differential systems, throttle etc. are either modified or

fabricated. Suspension system is generally not included in karts because of their low weights and small track widths, so instead of them shock absorbers are mounted. The electrical parts like motor, motor controller, battery, kill switch, arduino, LCD are installed finally. So the design stage is very crucial because of various dynamic problems such as manoeuvrability, braking & steering efficiencies that depend on the design itself. So, a safe and sound design is necessary. Failure of many subassemblies can result in putting the driver's safety at stake and imperilling the vehicle. So, a proper analysis of the sources of failures and their effects are to be done.

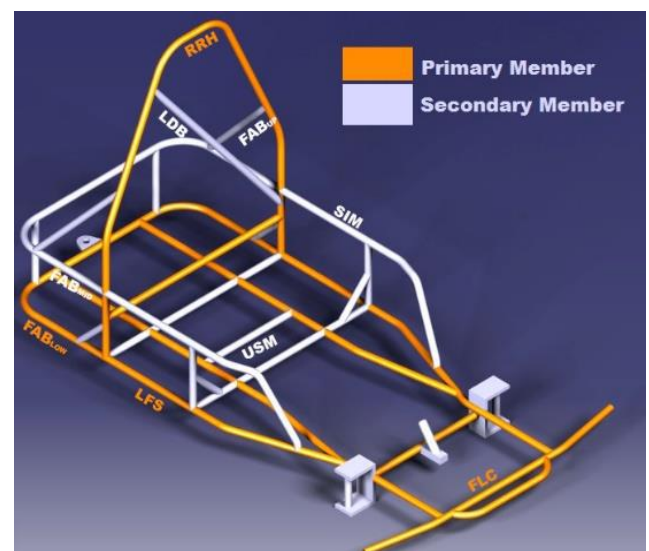


Fig. 1: frame of the kart with its various members

2. FAILURE MODES AND EFFECTS ANALYSIS

(FMEA)

American society of quality says that “Failure modes and effects analysis” is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service [5]. Failure modes mean the ways or modes in which something might fail. Effect analysis is the analysis of consequences of failures. Failures are given priority on the basis of risk of their consequences. Therefore FMEA ensures a systematic approach and gives aid in evaluating, tracking and updating the product or the system [6].

This technique was used by contractors for the U.S. National Aeronautics and space administration (NASA) in programs like APOLLO, VIKING, VOYAGER, MAGELLAN and SKYLAB [1]. FMEA has the following types-(a)Functional-which is based on a functional breakdown of a system and potential failure modes are found out & general mitigations are proposed to limit the consequence of failures.(b)Design-analysis of products prior to production are to be done& (c)Process-analysis of manufacturing assembly process are to be covered[1].

2.1 Design Failure Modes and Effects Analysis (DFMEA) & Risk Priority Number (RPN)

DFMEA is a disciplined analysis of the part design with intent to correct or prevent the design based failure modes prior to first production [7]. First of all, all the components of the electric-karts are identified and its relation with other components. After that, all possible potential failure modes of the components were found out. It is followed by identifying their effect on the component & its relative

component and the vehicle as a whole. The severity rank, likelihood of occurrence rank and detection rank are given to each failure mode (1-10) based on certain criteria that are given in Table 1, Table 2 & Table 3. The product of these three ranks will give risk priority number for the failure. It is a numeric assessment of risk assigned to a failure mode.

$$RPN = \text{severity ranking} * \text{likelihood of occurrence} * \text{likelihood of detection.}$$

Then, a graph of risk priority number for each point is plotted starting from highest RPN to lowest one in descending order. This graph helps to identify the part on which we have to focus more while designing.

2.2 Severity Ranking, Likelihood of Detection, Likelihood of occurrence

Severity shows the consequences a failure method. It considers the worst potential consequence of a failure of the kart. It is rated between 1 i.e., no effect to 10 i.e. extreme hazardous. Severity ranking with its description and effect is analysed in Table 1.

Likelihood of detection shows how likely the control will detect the failure mode. Similarly, it is rated from 1 i.e. almost certain to 10 i.e. absolute uncertainty. The likelihood of detection along with its description and rating is analysed in table 3.

Likelihood of occurrence shows the chances of various failures occurring in the components of the kart. The rating is done from 1 i.e. failure is unlikely to 10 i.e. persistent failures. Likelihood of occurrence along with its rank and possible failure rates are analysed in Table 2.

Table 1: severity effects with its rating and description

SL. NO.	SEVERITY EFFECT	SEVERITY DESCRIPTION	SEVERITY RANK
1	Extreme hazardous (without warning)	The concerned failure mode affects safe operation and/or involves non-compliance with government regulation without warning. Chances of jeopardising the vehicle are extreme along with compromise of driver's safety.	10
2	Hazardous (with warning)	Failure mode hinders safe vehicle operation and/or involves non-compliance with government regulation with warning. Kart is inoperable and driver's safety is at stake. Instant repairing not possible.	9
3	Very high	Kart is inoperable with loss of primary functions. Faults are detected easily but instant repairing not possible.	8
4	high	Kart is operable but performance level of the kart is extremely low. Major and necessary modifications are needed to enhance performance.	7
5	Moderate	Vehicle is operable but convenience options don't work smoothly.	6
6	Low	Principle operations work but performance level is reduced.	5

7	Very low	Concerned failure mode affects very little to the overall performance of the kart. Some modifications & repairance are needed.	4
8	Minor	Negligible effect on kart with nominal performance level.	3
9	Very minor	Very negligible effect on kart. Generally, no modification needed.	2
10	None	No effect.	1

Table 2: likelihood of occurrence of the failure mode with its ranking and rating

SL. NO.	PROBABILITY OF FAILURE	POSSIBLE FAILURE RATES	OCCURENCE RANK
1	Extremely high with persistent failure	1 in 2	10
2	Very high , almost inevitable	1 in 5	9
3	High with repeated failure	1 in 10	8
4	Moderate with typical failure	1 in 25	7
5	Moderate with frequent failure	1 in 100	6
6	Moderate with frequent failure	1 in 500	5
7	Moderate with occasional failure	1 in 2,000	4
8	Very low with relatively few failures	1 in 15,000	3
9	Remote	1 in 150,000	2
10	Nil	1 in 1,000,000	1

Table 3: likelihood of detection of failure mode with its definition and ranking

SL. NO.	LIKELIHOOD OF DETECTION	DEFINITION	DETECTION RANK
1	Absolutely uncertainty	Design control can't detect the major cause of failure mode.	10
2	Very remote	Very remote chances to find the cause of failure mode.	9
3	Remote	Remote chance that controls will detect the potential cause & then the subsequent failure mode.	8
4	Very low	Controls have very low chance to detect the potential cause/mechanism & subsequent failure mode.	7
5	Low	Poor chance of detecting failure by controls.	6
6	Moderate	Moderate chance of detecting failure by controls.	5
7	Moderately high	Moderately high chance of detecting failure by controls.	4
8	High	Controls will detect the failure mode with little deliberation.	3
9	Very high	Controls will detect the failure mode with almost certainty.	2
10	Certain	Detection of failure mode is certain.	1

3. RESULTS AND DISCUSSION

DFMEA is implemented on 17 critical components/assemblies of the kart. The detailed analysis is shown in Table 4.

Table 4: DFMEA implementation on critical components(S*=severity rank, O*=occurrence rank, Detection rank)

Sl. No.	COMPONENT	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT	S*	O*	D*	RPN =S*O*D	PREVENTIVE MEASURES
1	Frame	Disengagement and bending of roll-cage members.	Welding cracks, severe vertical and torsional twisting and bending forces.	Damage to roll over protection, vibrational shocks to motor, failing of frame, driver's safety is compromised.	10	5	8	400	Select the material of high factor of safety and yield strength, keep the tube thickness of primary members bit more than secondary members, weld properly without leaving any crack.
2	Bracket	Bending and breakage.	Various excessive loads causing the bending and bearing stresses severely high.	Instability of various roll-cage members like rear roll hoop & side impact members.	9	4	8	288	Select material of high factor of safety, weld properly without residual cracks.
3	Brake	Long pedal travel, poor braking, brake pulling i.e. kart pulls to one side.	Leaking master cylinder/brake pipe line, air in the system, low fluid level in master cylinder, badly aligned shoes, bending of brake pedal.	Inefficient braking, speed of the kart is reduced, driver's safety compromised.	8	6	8	384	Periodic brake bleeding followed by keeping the bleeder screw tight, reline the shoes properly, reservoir of master cylinder should be always filled, keep pipeline leakage free, select standard pedal.
4	Steering (considering both rack & pinion and bell-crank type) [8].	Hard steering, looseness in steering, car wandering, shimmy front wheels, scuffed tyres, steering wheel jerking.	Too tight steering gear, incorrect/insufficient lubrication, incorrect caster, camber, king-pin inclination and toe-in, low tyre pressure, worn tie rod ends, welding cracks.	Abnormal response, steering failure, driver's safety compromised.	9	7	6	378	Proper lubrication between rack and pinion and at tie rod ends, weld properly, tie rod pins should be fastened correctly.
5	Tires	Side wear and damaged beads, puncture, excessive wear in the centre of tread,	Excessive wheel camber, wheel misalignment, under/over inflation, faulty valve or	Kart runs bizarrely, reduced steering response,	9	5	7	315	Frequent bleeding, proper wheel alignment, tire replacement if required, choose

		cuplike depression on one side of trade.	leakage in tube patch, loose steering linkage, foreign debris.	driver's safety is compromised, and tire life is decreased.					the tire type based on road conditions.
5	Rim	Brittle or ductile fracture, rim-out.	Impact loads, foreign transverse excessive load.	Abnormal response to steering, damage to the axles and the frame, driver's safety compromised	6	2	10	120	Use standard rims, never put unnecessary transverse loads on the wheel, check and repair the flanges in case of rim-out.
6	Knuckle	Bending of the steering arm, structural cracks.	Fatigue load and impact load, cyclic load, improper mounting [9].	Poor response to steering reducing operability of kart, malfunctioning disc brake callipers.	7	2	6	84	Mount the knuckle carefully; choose a standard knuckle & if required fabrication then select the material of high FOS. Rivet properly with modified arms, proper lubrication in joints.
7	Transmission	Noise between the link pins of chain and sprocket, breakage in chain, mechanical failure in differential (bevel) gears.	Insufficient lubrication of gears and chain-sprocket drive and drive shafts, improper mounting, excess torsion in drive shaft.	Abnormal behaviour of kart, operability is reduced, decrease in speed, sudden shocks due to worn gear teeth, sagging, reduction in driver's safety.	8	5	5	200	Mount all the necessary parts carefully & rigidly with primary members, chain drive arrangement should not be horizontal/vertical completely.
8	Supports	Disengagement from roll-cage members.	Welding fracture at the ends of the support, bending.	Instability of roll-cage members.	7	2	10	140	Select the material of high factor of safety and weld properly.
9	Bumper/ Shock Absorber	Structural failure.	External impact load exceeds the yielding limit of the material.	With failing bumper further impact load can damage FLC [4] and the kart as a whole.	5	2	5	50	Choose a material of high factor of safety, clamp/rivet properly with FLC.
10	Body Panels	Dents or breakage.	While fabrication inappropriate mixing proportion of resin and hardener, insufficient number of fibreglass sheets to be laminated for a panel.	Loss in aesthetics.	4	3	6	72	Be careful while mixing the resin with hardener. Always use 3-5 glass for lamination for a panel.

11	Motor	Winding rupture, short circuit, rotor and stator faults, bearing failure [9].	Improper installation, vibrational shocks, overloading, presence of foreign debris, erroneous lubrication of drive gear.	Rpm decreases, abnormal starting, overheating that can block bearings and damage it, repair cost increases	6	3	2	36	Connections are carefully done, inspect motor mount & bolts and nuts, and check for any misalignment.
12	Motor Controller	Short circuit in any component, failure in any component.	Faulty connections, BIOS incompatibility, failure in bipolar junction transistor.	Motor doesn't start Rpm variations.	5	2	2	20	Connections are checked properly, repair electrical component if required.
13	Battery	Separator failure, short circuit, electrolyte loss, electrolyte stratification [10].	High temperature, high charging rates, overcharging, improper insulation of wires and their connections, inefficient battery casing.	Reduced performance and in some cases not operable at all.	4	5	2	40	Always check wire connections and their insulation, battery casing. Don't overcharge.
14	Throttle Pedal	Disengagement from fore aft bracing (low), signal sent by throttle pedal to motor is hindered.	Improper welding, excessive pedal effort from drive, wiring between pedal and motor controller is halted.	Speed of the motor shaft is decreased	4	3	2	24	Weld efficiently; check the wiring thoroughly with proper insulation.
15	Driver Seat	Structural failure in the seat frame, disengagement from the lower frame.	Inefficient welding of the seat frame and between the seat frame and lower frame of the kart.	Driver's safety is compromised	6	2	5	60	Choose a material of high factor of safety for seat frame, welding should be done without leaving any fractures.
16	Arduino	Wrong display of battery life and speed in the LCD.	Short circuit in its components, wiring problems, wrong program code.	Kart's running speed is not measured, sudden stoppage of kart as battery drains but driver is unknown to it.	3	6	7	126	Wirings should be checked and thus corrected with proper insulation. Program code should be written correctly.
17	Kill Switch	Electrical failure.	Short circuit, wiring problems, improper insulation, vibrational shocks.	Vehicle becomes inoperable.	3	5	7	105	Check wirings frequently, proper installation to prevent shocks.

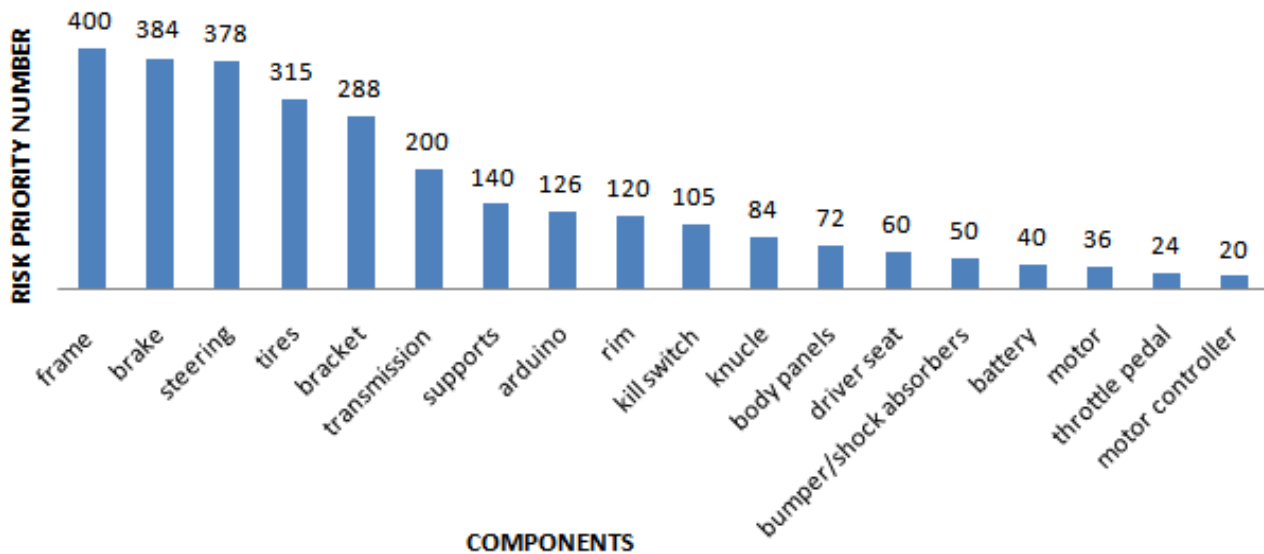


Fig 2: RPN (risk priority number) graph

Priority chart for components is prepared based on their risk priority number (Fig. 2). The components/assemblies that have higher RPN such as frame, braking system, steering assembly, tires, brackets and transmission assembly should be given more priority and attention while designing and fabrication as they are more suspected to failure. Possible preventive measures for different components regarding their failure modes are also listed out in the DFMEA implementation table to control the risks up to a certain point.

4. CONCLUSION

DFMEA is successfully applied to various components of an electric kart listing out all their possible failure modes and their causes. Based on the likelihood of occurrence, likelihood of detection and severity effects of the failure modes Risk Priority Number for the components was computed followed by a priority graph in which components are prioritized according to their risk priority number.

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BIOGRAPHY



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