CHAPTERONE

INTRODUCTION

1.1 General:

The Sudan has great agricultural resourcessuch as arable lands, water resources,livestock, forests and vast natural resources,so it is considered to be one of the most suitable areas to grow many crops such as millet, wheat, sesame cotton and sugarcane.

Sugar cane is one of the most important mechanized agricultural crop in the Sudan in terms of economic returns. In addition to sugar production, can growing allows the possibility of manyby products such as molasses and its derivatives, animal feed, paper and cardboard industry.

Mechanized agriculture is the process of using agricultural machinery to mechanize the work of agriculture, greatly increasing farm worker productivity. In modern times, powered machinery has replaced many jobs formerly carried out by manual labour or by working animals such as oxen, horses and mules. Mechanization is an important tool for profitable andcompetitive agriculture production (sugarcane plantation). The needfor mechanization is increasing fast with the decrease of draft power. Withoutmechanization it will not be possible to maintain multiple cropping patterns, which need quick land preparation, planting, weeding, harvesting, processing etc.

1.2 Background and Justification:

One of the most important factors in obtaining thehighest crop yield of sugarcane is time, as an operation performed at an improper time may cause the loss ofpotential yield so,under a particular combination of weather, soil type, topography and other related factors, there is anappropriate time to perform a particular field operation sothat both the quality and quantity of a product reaches an optimum level

Today, sugarcane harvester is one of the most important powers sources in sugarcane plantation and represents a major componentof farm fixed costs with its main share in planting.

Prediction of sugarcane harvester performance is important machinery utilization and management issue, especially when considering the peculiarities of a agricultural machinery. In most of agricultural schemes of the Sudan machinery maintenance was not given much attention. These resulted in high percentage of this machinery not to work on good condition and were out of work. On the other hand lack of proper maintenance and unavailability of spare pare reduced the time life of harvester.

The case can be evidenced by the variety of makes and types and size of tractor imported into the Sudan. Moreover, it can be visualized by the timing of the viscous cycle of new death of large number of tractor and renewal number of the tractor importation. Moreover the improper records about tractor repair and maintenance makes difficulties for making correct maintenance management.(**Omran**, 2010).

To correct and upgrade level of machinery maintenance and upkeep them, new policesit's neededto be formulated and new procedure need to be adopted. This is critically and urgently required in Sudanese company sugar cane plantation for proper time matching of the factory daily capacity and field cultivation and harvesting operation.

1.3 Study objectives:

The general objective of this study is to develop and improve the operation of sugarcane harvester machine by adjustment maintenance management, forthe purpose of increasing reliability and availability of harvester life time cycle, decreasing cost of maintenance and repair, by developing an analytical, user- friendly computer model for harvester failure analysis maintenance management as an aid for farm managers, agricultural engineers and decision-makers.

The specific objectives of this study are:

1. To display appropriate model of repair and maintenance of sugarcane harvestersfailure depending on the current maintenance policy, quality and schedule field operation by analyzing failure history, using Gamma Distribution theory.
2. To apply the model of failure analysis on two sugarcaneharvesters'models, on two agricultural schemes workshops namely, Guniedand New Halfa sugar farm.
3. To calculate dependability and availability indicators.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sudan Farming Systems:

The Sudan is the largest country in Africa; it lies within the tropical zone (latitudes 3º and 22º North and longitudes 22º to 38º East), with a total land area of more than 2.4 million km^2. Traversed from north to south by the two great Blue and White Nile rivers, it is one of Africa's most geographically diverse countries, with mountains, desert, swamps and rainforest. The southern part of the country is tropical; the north is an expanse of arid desert. Rainfall is erratic and drought occurs periodically in some regions. The current population according to the World Fact book the July 2006 population estimate was 41,236,378 with a 2.55% growth rate and low population intensity of individual per kilometer. Sudan economy depends on agricultural, and characterized by a wide range of agro-climatic zones and thus different farming system. (Ibrahim, 2006)

The main farming systems are: Irrigated System: This system includes areas irrigated from the Nile and its tributaries, flush-irrigated areas, and irrigated from bore-wells. The total area under this sector is estimated at 4.89million Hectares. This sector is dominated by large national schemes like Gezira, New Halfa and Rahad and sugar factories. The size of tenancies range from 4.20 to 16.8 hectares. Mechanized rain fed system: This system covers areas in the central clay plain. Mechanization is practiced in land preparation and threshing. The total area in this sector is estimated at 6.3 million hectares, with average size of holdings of 420 hectares. Traditional rain fed system: This system covers all areas under traditional production where non-mechanized agricultural tools are predominantly used. It is characterized by a small farm size, labor-intensive cultivation techniques employing hand tools, low input levels, and poor yields. Crops grown in the rain fed sector include sorghum, millet, sesame, sunflower, and groundnuts.

2.2 Agricultural Mechanization and Machinery Management:

Agricultural mechanization in its broadest concept is the use of machinery in agricultural production; it is the mechanical power for performing different agricultural operations which include land preparations, seeding, weeding, pesticides and chemicals application, harvesting and post harvest operations, as well as soil reclamation.

Agricultural machinery management and maintenance is one of the important branches of farm management. Deciding considering replacement time of farm machinery noted to conditions of their economical and technological is one of the considered aims in management of farm machinery. A complete line of machinery is one of the largest investments that a farm business can make. Yet, unlike land or buildings, machinery must be constantly monitored, maintained, and eventually replaced. How and when equipment is replaced can mean a difference of thousands of dollars in annual production costs (**Singh**, 2006).

The need for proper machinery management becomes even more important when one considers the cost of owning and operating agricultural machinery, farming requirement of soil and crops, and economic conditions. The select of agricultural machinery and scheduling their use depends primarily upon the ability to predict available working time for field operations during the cropping season(**Singh**, 2006)

Mechanization is thought to be the possible instrument to cultivate, the vast areas and enhance development of rural communities in the all these types of farming systems. Hence medium tractors and combine harvesters are introduced to cultivate mono cropping system of rainfed areas using wide level discs and for transport of domestic water and crop proceeds. Corrective maintenance is carried at season end when it is unavailable during time of land perpetration. Preventive maintenance is not usually done on predetermined schedule. The actual result of this practice is short tractor life span and early death rate. Similar trend is observed in irrigated farming system and varieties of machines are introduced. The levels of mechanization in each one of the irrigated schemes differ according to type of crop rotation, available working days and maintenance and replacement policies used.

Machinery management decisions are the most important in today's agriculture. Their importance gets from the long term effect they have and the high proportion of total production costs increased by farm machinery. These decisions are extremely important in developing countries where purchaseits price of agricultural machinery is considerably high, and coupled with scarce spare parts. (**AbdElkraim**, 2001)

According to **FAO** report, (2008) the purpose of an agricultural mechanization strategy (AMS), is to create a policy, institutional and market environment in which farmers and other end-users have the choice of farm power and equipment suited to their needs within a sustainable delivery and support system. “Farmers and others” refer to all end-users of farm power, tools and equipment, such as small family operated farms, commercial farm businesses, farmer's organizations, irrigation groups, contractors, government operators and primary agricultural produce processors. AMS deals with manual, draft animal, mechanical power, the utilization of tools, implements, machinery, and their supply and maintenance.

reported that the main objective of mechanization is to increase the production by timely operation and effective work, sometime due to lack of labor; particular operation cannot be done at the stipulated time, which in turn affects the growth and ultimately declined production. The use of machines and implement save the labor and reduces the time of operation. It helps in performing the operation timely and also increases the area of cultivation. The introduction of machines will not only make agriculture more acceptable but will also provide opportunities for the use of higher intelligence, skill and initiative. Most of the farm operations are labor intensive and are perform with the use of small tools made of wood and steel.**(Adigun**, 2004)

2.3 Sugar Cane Productionin Sudan:

The republic of the Sudan is considered to be one of the most suitable areas for growing sugarcane, due to its favorable climatic conditions as the summer is a long season with high temperature and plenty of sunshine more than 12 hrs a day. The winter as well is relatively cool, this in addition to the vast well leveled clay soil bounded by the Blue Nile River from the east and the White Nile River from the west. The rainfall per annum is ranging from 300 mm to 500 mm. Sugar industry in the Sudan started in the early 60s with the Guneid sugar factory followed by New Halfa sugar factory. Before Kenana factory was erected another two sisters sugar factories have been built at Sinnar and Assalaya. Commercial production of sugarcane started in Sudan in 1962 with the establishment of the Guneid factory which is followed by New Halfa, Assalaya, and Sennar .Each factory and its farm is operated by administration body. All these four factories are owned by the government of Sudan and controlled by one centralized management body: the Sudanese Sugar Company (SSC). El Guneid factory is the only sugar estate in Sudan that works on tenancy bases, while all other two sugar estates are integrated companies. The fifth sugar factory is Kenana Sugar Factory which established in 1981 as a private company owned by ten shareholders. Although the sugar schemes share similar agro-ecological conditions and generally lies within the central clay plains of the Sudan it is often reported that the performance of Kenana factory is better than each one of the state owned factories. Management and operation of agricultural machinery in all sugar schemes is controlled by a specified unit within each scheme. The methods of land preparation in these schemes are almost the same but methods of cane harvesting in Kenana are different from that of state schemes.Land preparation is done during the period September to December /January over 24 hours work in three shifts. Its main objectives are to destroy and incorporate the residues and stubbles of the previous crop cycle into the soil, aerate the soil and improve its physical and chemical properties, create smooth and level soil surface, and ease the subsequent operations of ridging, covering of stem sets, incorporation of fertilizers, green manure and soil amendments, irrigation, germination of seedlings and root development.(**Mohammed,** 2008).

Harvesting is a critical operation in sugarcane production. Harvesting begins with the drying of the fields. Irrigation water is usually stopped at least one month before harvesting. Drying is followed by a number of preparatory operations; these are opening of fire lines, breakage of water banks and road for the movement of the harvesters and transportation machinery.

Harvesting process includes much type of equipment and implement according to method of harvesting as tractor with trailers and Grab loader, or trucks with mechanical harvester.

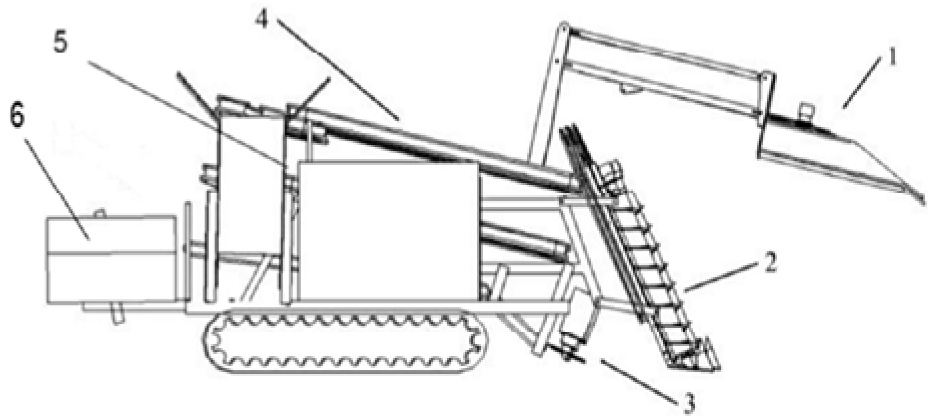
In Sudan sugarcane is harvested manually or mechanically, mechanical harvesting includes multi-operations: crop cutting, hauling and transportation to the factory. In the past whole stalk harvesters are used to cut sugarcane crop just above soil surface leaving the whole stalk intact. The whole stalks are then burned, loaded into trailers and hauled to the mill.

Harvested sugarcane in the state plantations is transported to the Trans loading site and later transferred to the mill using trailers while in Kenana private plantation wagons are used. The whole stalk harvesters were now replaced by combine harvesters. These harvesters cut burned cane crop stalk into 12-14 inch billets and directly load the cut canes into wagons or trailers running by the side of the harvester. New combines that harvest green canes were not yet introduced into the Sudan. It is argued that combine harvesters that can harvest green canes had the advantages of deposition of organic matter into the soil and thereby improves soil physical conditions, conserve soil moisture, control weeds and save cost of crop cultivation. In contrast, it is believed that dead sugar cane leaves left unburned in the field under dry hot summer conditions increase growth of termites. (**AbdElkraim**, 2001)

2.4. Importance of using sugar cane harvester:

A sugarcane harvester is a large piece of agricultural machinery used to harvest and partially process sugarcane. The machine, originally developed in the 1920s, remains similar in function and design to the combine harvester. Essentially a storage vessel on a truck with a mechanical extension, the machine cuts the stalks at the base, strips the leaves off, and then cuts the cane into segments. These are then deposited into either the on-board container, or a separate vehicle traveling alongside. Waste material is then ejected back onto the field, where it acts as fertilize. (**Arjona**, 2001)

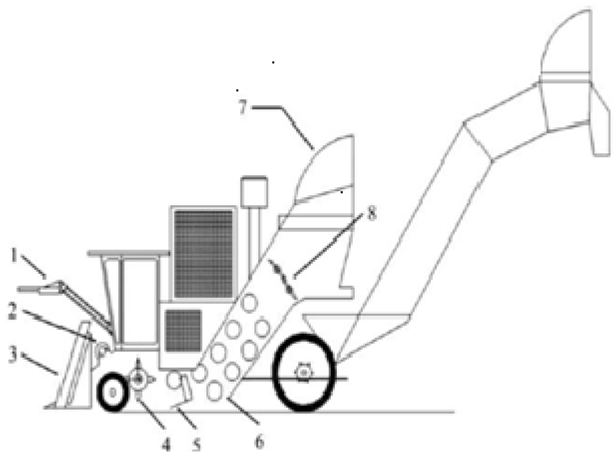
Generally, sugarcane harvesters can be categorized into whole stalk harvesters and chopper harvesters.A typical whole stalk harvester system consists of a topper, a base cutter, a feeding mechanism, and a discharging mechanism (Fig2.1)



: (1)topper(2)crop divide and lifter (3)base cutter(4) conveying device (5)defeating device(6)cane collector

Fig 2.1 Atypical whole stalk harvester system

The topper is designed to sever cane tops and then discharge the severed tops to the side of harvesting rows. Topped cane stalks are then cut by the base cutters at about 30 mm above the ground level (**Esquivel** et al., 2008). Then feeding mechanism includes a set of rollers to convey the cane stalks to the discharging mechanism. The discharging mechanism then delivers harvested stalks to either a wagon or onto the field. The other type of harvester is the chopper harvester. Except for the components of whole stalk harvesters, chopper harvesters include extra components such as chopper and extractors. The functionality of the chopper and extractor are to chop whole stalk into billets and separate leafy materials. In the harvesting process by chopper harvesters, the discharging mechanism is used to deliver the billets to a wagon or a truck. (Fig.2.2)



(1) Topper (2) (3)crop divider (4) fin loller (5) base catter (6) feeding rollers

(7) primary extractor (8) chopperr

Figur 2.2 Atypical chopper harvester system

2.5. Maintenance Concepts:

Wall, (2006) defined maintenance as the activity of equipment/item maintenance that develops concepts, criteria, and technical requirements in conception and acquisition phases to be used and maintained in a current status during the operating phase to assure effective maintenance support of equipment.

As defined by **Laskiewicz**, (2005) the maintenance functions includes:

*Inspection: determine the serviceabilityof an item by comparing its physical, mechanical and/or electrical characteristics with established standards through examination test.

*Verification: to verify serviceability and detect incipient failure by measuring the mechanical or electrical characteristics of an item and comparing those characteristics with prescribed standards, or service.

* Correction: Operations required periodically keeping an item in proper Operating condition

Wall, (2006) reported that maintenance is an important part of the life-cycle of embedded systems, and must be considered from the design stage through the end-of-life stage of the system. Maintenance covers two aspects of systems; operation and performance. Maintenance is generally performed in anticipation of, or in reaction to failure. Maintenance is performed to ensure or restore system performance to specified levels. Moreover, maintenance operations have been categorized based on their frequency and their motivating factors. Four of the most common designations are described as; predictive, preventative, corrective and fault-finding. Predictive maintenance involves a series of steps prior to actually performing maintenance. It begins with sampling physical data over time, such as vibration or particulate matter in oil. Analysis is then performed on the collected data to create an appropriate maintenance schedule, and maintenance is performed according to the schedule. This type of maintenance analysis works well for mechanical systems because the failure modes are well understood. Additionally there is historical data useful for creating and validating performance and maintenance models for mechanical systems. Preventative maintenance refers to maintenance performed when a system is functioning properly to prevent a later failure. Generally, it is performed on a regular basis and maintenance is performed regardless of whether functionality or performance is degraded. The frequency of the maintenance is generally constant, and is usually based on the expected life of the components being maintained. One common example is lubrication of mechanical systems after a certain number of operating hours, another is replacement of lightning arresters in jet engines after a certain number of lightning strikes.

Corrective maintenance refers to maintenance done to correct a problem when something has failed, or is failing. The need for corrective maintenance can be beneficial or detrimental depending on the product and the profit model used during the design phase of the product. On the most obvious level, corrective maintenance is detrimental to operation because it means that something failed, and the system is not available during the time needed to perform the maintenance. On the other hand, it may be that the economics and planned functionality of a system are such that using a cheaper, replaceable device for which failure is anticipated, makes sense. Failure-finding maintenance involves checking a (quiescent) part of a system to see if it is still working. This is most often performed on portions of a system dedicated to safety protective devices. This is an important type of maintenance check to perform because failures in safety systems can have more catastrophic effects, if other parts of the system fail (**Singh**, 2006).

2.5.1Typpes of maintenance:

(Bowler, et al 1999) define two type of maintenance, first; Preventive maintenance defined as conducted to keep equipment working and/or extend the life of the equipment, second; Corrective maintenance, sometimes called "repair", is conducted to get equipment working again.

(Ben, et al 2000) summarized the advantage and disadvantage of preventive maintenance as:

a) Increased component operational life span.

b) Decrease in equipment or process downtime.

c) Decrease in costs for parts and labor.

d) Better product quality.

e) Improved worker and environmental safety.

f) Improved worker moral.

g) Energy savings.

h) Estimated 8% to 12% cost savings over preventive maintenance program.

While the disadvantages increased investment in diagnostic equipment, increased investment in staff training and savings potential not readily seen by management.

(Jagannathan et al 2000) defined Preventive maintenance as: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level. The Advantages of Preventive Maintenance is cost effective in many capital intensive processes, flexibility allows for the adjustment of maintenance periodicity, increased component life cycle, energy savings, reduced equipment or process failure and estimated 12% to 18% cost savings over reactive maintenance program on the other hand disadvantages of preventive maintenance is catastrophic failures still likely to occur, labor intensive, includes performance of unneeded maintenance, potential for incidental damage to components in conducting unneeded maintenance of the system working state.

2.5.2 Maintenance Management:

Management characterizes the process of leading and directing all or part of an organization, often a business one, through the deployment and manipulation of resources (human, financial, material, intellectual or intangible). One can also think of management functionally as the action of measuring a quantity on a regular basis and adjusting an initial plan and the actions taken to reach one's intended goal. This applies even in situations where planning does not take place. Situational management may precede and subsume purposive management. Maintenance management will therefore characterize the process of leading and directing the maintenance organization. (Kijima, (1998) (Desai, (2006) reported that maintenance management is an orderly and systematic approach to planning, organizing, monitoring and evaluating maintenance activities and their costs. A good maintenance management system coupled with knowledgeable and capable maintenance staff can prevent health and safety problems and environmental damage; yield longer asset life with fewer breakdowns; and result in lower operating costs and a higher quality of life. Depending on the application and design of a maintenance system, the format and steps of preparing a maintenance plan can vary.

2.6 Concepts of Failure Analysis:

(Berg, 1990), defined failure basically as the termination of the ability of a component/part to perform its required functions. The failure of component/system can be classified in many ways, which may include: catastrophic, performance, deliberate, random and time-depended failure.

(Mishera, (2006) stated that failure classification may be viewed from different aspects according to the effect; it will have on the overall performance of the equipment/system. Broadly, failures are classified as:

(i) System failure, and

(ii) Component failure.

The engineering classification of failures may have:

(i) Intermittent failure, which may result in lack of some function of the component only for a very short period of time, and

(ii) Permanent failure, where repair/replacement of component will be required to restore the equipment to operational level.

When considering degree of failures, it can be classified as:

(i) Complete failure, where equipment/system is inoperative and cannot be used further, and

(ii) Partial failure, which leads lack of some functions but the equipment/system can be used with care, may be with reduced performance.

(Mishera, (2006) reported that some failures can be sudden and cannot be anticipated in advance, whereas, the gradual failures can be forecasted during inspection/testing, which follows the part of the condition monitoring. Other classification of failure can be:

(i) Catastrophic failures, which are both sudden and complete;

(ii) Degradation failures, which are both gradual and partial.

Failure rates analysis and their projective manifestations are important factors in insurance, business, and regulation practices as well as fundamental to design of safe systems throughout a national or international economy. In words appearing in an experiment, the failure rate can be defined as: The total number of failures within an item population, divided by the total time expended by that population, during a particular measurement interval under stated conditions. Here failure rateλ (t) can be thought of as the probability that a failure occurs in a specified interval, given no failure before time (t). It can be defined with the aid of the reliability function or survival function R (t), the probability of no failure before time (t), as:

a- Formula where t_1 (or t) and t_2 are respectively the beginning and ending of a specified interval of time spanningλ (t), this is a conditional probability, hence the R (t) in the denominator. By calculating the failure rate for smaller and smaller intervals of time, the interval becomes infinitely small.

b) Formula Continuous failure rate depends on a failure distribution, which is a cumulative distribution function that describes the probability of failure prior to time (t),

c) Formula that failure distribution function is the integral of the failure density function, f(x),

d) Formula that the hazard functions can be defined as z(x).

e) Formula for many probability distributions can be used to model the failure distribution. A common model is the exponential failure distribution.

f) Formula which is based on the exponential density function.

g) Formula For an exponential failure distribution the hazard rate is a constant with respect to time (that is, the distribution is "memory less"). For other distributions, such as a Weibull distribution or a log-normal distribution, the hazard function is not constant with respect to time. For some such as the deterministic distribution it is monotonic increasing (analogous to "wearing out"), for others such as the Pareto distribution it is monotonic decreasing (analogous to "burning in"), while for many it is not monotonic.(**Mishera**, (2006)

(Ahmed, et al (1999) described standard model established for the prediction of repair and maintenance cost of the medium-size, two-wheel drive, diesel engine tractor in Sudan. The model was derived based on data collected over a ten-year period, from several locations in Sudan, and it predicts repair and maintenance costs as a power function of tractor cumulative use in hours. The model showed that the tractor cumulative use in hours was the major determinant of the tractor repair and maintenance costs. It also revealed that a number of other factors, which were not quantified in this study due to lack of information, influenced repair and maintenance costs but to a lesser degree as compared to cumulative use. Those factors include:

maintenance management; operator skill and attitude; working conditions; availability of replacement parts at the appropriate time; and tractor design features. Comparison of Sudan standard prediction model with similar models established in some industrial and developing nations revealed that the estimates of repair and maintenance costs of the agricultural tractor in Sudan were significantly higher when compared with industrial countries. However, when compared with other developing countries, there was no significant difference between the estimates for Sudan and those of other developing countries.

(Kenne, et.al 2006), defined Probability as measures the uncertainty about the occurrence of a particular event or a set of events and is expressed numerically before zero and one. This can be estimated by any of the three methods as:

1. Objective approach, which could be classical or empirical.
2. Subjective approach, where probability measures the degree of confidence.
3. Modern approach, which combines both the approach, cited above and are based on the theory of sets.

The mathematical definition of a discrete probability function, p(x), presented by Richard, (2000) as a function that satisfies the following properties:

1. The probability that x can take a specific value is p(x) is:

$$p(x) = p_z \text{ ---------------------------------2.1}$$

p_z is non-negative for all real x.

2. The sum of p(x) over all possible values of x is 1, that is

$$\sum_j P_x = 1 \text{ -----------------------------------2.2}$$

Where:

J= represents all possible values that x can have. $P_{x=}$ is the probability at x_j.

(Mishera, (2006) summarized commonly used distributions for failure/repair analysis of engineering systems, which enable to estimate parameters based on statistical analysis of the equipment/system performance as:

A- Normal distribution: its continuous probability distribution, the probability density function for this distribution is:

$$f(x) = \left(\frac{1}{\sigma\sqrt{2\pi}}\right) \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \text{-------------------2.3}$$

Where:

μ = population mean.

σ = standard deviation

x = real number denoting random variable.

B- Log normal distribution: it is the distribution of a random variable whose natural logarithm follows a normal distribution as:

$$f(x) = \frac{1}{\sigma x\sqrt{2\pi}} \exp\left[\frac{\ln(x-\mu)^2}{2\sigma^2}\right] \text{-------------------------2.4}$$

Where:

x> 0

μ and σ may give by:

$$\mu = E\,(\ln x) \text{ ---------------------------------2.5}$$

$$\sigma = V\,(\ln x) \text{ -------------------------------------2.6}$$

Where:

E (ln x) = Mean function

V (ln x) = variance function

C- Poisson distribution: it is more useful, where number of trials or experiments is high and the probability of occurrence of an event is small. The general expression for this can be given as follows:

$$f(X) = \frac{\lambda^{x}.e^{-\lambda}}{x} \text{ --------------------------------2.7}$$

Where:

x = 1, 2, 3, ∞

x has a Poisson distribution with parameter, which must be positive. The important property of this distribution is that the expectation and variance are equal to each other.

D- Gamma distribution is sometimes used to represent various types of maintenance time data. The distribution probability density function is defined by:

$$fR(x) = \frac{\lambda^{\beta}}{\Gamma(\beta)} t^{\beta-1} e^{-\lambda t} \text{ ……………………..2.8}$$

Where

λ = scale parameter

β = shape parameter

Γ(β) = gamma function

Availability is defined by (**Co**, (2006) as the fraction of time that a device or system is able to perform its required function. The term availability can be used additionally in other two distinct senses: firstly, as the probability that a system works on demand (appropriate for safety protection systems or for standby systems which are required to function on demand); and finally, as the probability that the system is working at specific time (t) (appropriate for continuously operating systems or components whose failure is revealed).

The common definition is relevant for estimating the productivity of manufacturing processes. In this situation the fraction of the time that the system is operating can be used to estimate the total output and, therefore, the expected revenue in any time period. In this case the system availability (A) is represented as:

$$\mathbf{A} = \frac{\mathbf{UPTIME}}{\mathbf{UPTIME+DOWNTIME}} \quad : \text{--------------------------------- } 2.9$$

Where:

UPTIME: Average time the system was up and operating,

DOWNTIME: Average time the system was down for corrective maintenance actions.

In the specific case in which the failure and repair distributions are dominated by the exponential distribution with constant failure rate (λ)and repair rate (μ), the expression for the availability, for the steady state, is given by the mean time to failure (MTTF) and mean time to repair (MTTR):

$$\mathbf{A} = \frac{\mathbf{MTTF}}{\mathbf{MTTF+MTTR}} \quad : \text{--- } 2.10$$

The mean time to failure (MTTF) is given by the reciprocal of the failure rate

(λ):$\mathbf{MTTF} = \frac{\mathbf{1}}{\boldsymbol{\lambda}}$:--2.11

Similarly, the mean time to repair (MTTR) is given by the above equation as:

$$\mathbf{MTTR} = \frac{\mathbf{1}}{\boldsymbol{\mu}} : \text{-- } 2.12$$

CHAPTER THREE
MATERIALS AND METHOD

3.1. Study area:

This study was carried out in two terms of the Sudan states, namely Kassala and Gezira states,the two states are situated insemi-desert zoneand savanna zone. This zones has rainfall <300 mm/annum hence rain-fed cultivation is limited to traditional farming on the ‘Qoz’ sand (mainly millet) and areas with higher clay content where water harvesting is practiced to grow sorghum and millet. Irrigated agriculture utilizing water from the Blue Nile, the White Nile and Atbara River is practiced on large scale schemes, e.g. Gezira, New Halfa, Rahad, Suki, Gunied, Blue, and White Nile Agricultural Schemes.

Kassala state lies between altitude 15 - 17˚ North, longitude 35 - 36˚ East with approximately a length of 115 km, and width of 30 km.The soil of the area is vertisol with clay content of about 45 – 60%, and with PH ranging from 7.8 to 8.07, the annual rainfall varying from 200-300mm, the highest temperature is 42˚C in May and lowest temperature of 14˚C in January. NewHalfasugarcane factory located in thisstate, some 400 km to the east of the capital of the SudanKhartoum.Also it was a German made. The factory started its commercial production in the season 1965/66. The crushing capacity is 5.5 thousands metric tons /day and the annual production capacity is nine thousands MT of refined sugar. The irrigation system uses canals branching from Khashm El Girba Dam. The dam was constructed on the west side of river Atbra, one of River Nile tributaries(**Adam**, 2001)

Gezira state is the most agriculturally productive state in the Sudan, bounded by Khartoum state in the North, Gadarif state in the East, White Nile state in the West and Sinnar state in the South. It lies in the rich Savanna region within latitude 13-15.20 N and longitude 32.5 – 340 E The area has a hot dry summer from April to June with daily temperature between 32^0C to 42^0C and relative humidity of 20%. The rainy season starts in late June and ends in October. Gezira Agricultural Scheme is one of a big scheme on Gezira state was founded in 1913 covering an area of 153,415 hectors.

El Gunied sugarcane factory located in the Gezira state on the eastern bank of the Blue Nile, some 150 km south east Khartoum, The factory is a German made with designed crushing capacity of four thousands metric tons/day and an annual production of six thousands MT of refined sugar. The production was fluctuating around 50% of the annual production capacity. In 1998/1999 the factory exceeded the production capacity by 16%, since then, the production never below the production capacity. ElGunied factory is the only sugar estate in Sudan works on tenancy bases, while all other sugar estates are integrated companies whereas the company owns both the factory and the farm as well. El Gunied is irrigated through pumps from the Blue Nile River. **Bakri (1998)**

3.2 Study sites:

New Halfa and Gunied sugarcane factories werefollowed by the Sudanese Sugar Company;Gunied is the first unit to come into existence in the year 1962. The initial goal in starting such unit was to meet the local sugar demand, reduce import of white sugar and thereby reduce foreign exchange load on the exchequer.

Generally inGunied factory farm there is one main workshop and some of sub-main workshop which are involved in the maintenance and repairs of agricultural machinery, Harvesters and tractors, workshops of factory provides maintenance and upkeep to various types of heavy agricultural machinery and equipments used for earth moving, land preparation and cane haulage purposes, and they are as follows:

a. Heavy machines workshop:

This workshop is located behind factory. It’s a modern and big workshop where engine, gearbox and transmission of heavy machine as Crawler tractor (D7 and D8) overhauls and carried out.

b. Wheel – tractor workshop:

The main wheel tractor workshop located with heavy machine workshop and its undertakes major tractor repair only (Structure maintenance). Its include different department as electric, hydraulic, welding and tiers departments workshop, the main data was collect from this workshop as defined later.

c. Agricultural machinery workshop:

This workshop undertakes the maintenance of agricultural machinery namely ploughs seeders and all other tools and equipment that using on the field. The farm workshops are distributed over the administrative blocks of farm factory.

There are mobile workshops to repair partial failure that may be occurring on the field.

The New Halfa Sugarfactory like Gunied Sugar factory manages by Sudanese Sugar Company follows and includes many type of agricultural machinery workshops as:

a- The Heavy Machineries Section: Undertakes the maintenance of the heavy machineries and loaders and provides the requirements of the machinerie which prepare the soil.

b- Trucks Section: Responsible for maintaining all trucks which pull the cane trailers and preparing the soil for planting the canes

c- Vehicles Section: This section maintains the factory’s cars and follows up and carrying out the periodical check up for all vehicles in different sections of the factory.

d- Trailers Section: Responsible for manufacturing the cane trailers and following up their maintenance making them ready before and after the season, there is also a modernized section for tires repairs.

e- Protective Maintenance Section: This section carries out the checkout of all moving machineries besides setting a program for their maintenance (engine oil change spare parts and others) it has to report monthly about the condition of the machineries to the agricultural workshop.

f- Blacksmith Shop: There is a blacksmith shop comprising of three workers for forging the different hand tools required for the manual fieldwork. These include; weeding hoes, shovels, sickles, diggers, axes, soil augers and weeding points for tractor cultivators in addition to several different hand tools for different uses.

Machine Shop: The machine shop comprises of five equipment these are: -G,

(i) Guillotine for cutting of steel plates.

(ii) Steel worker for cutting of small sizes of angles, tubes and bars.

(iii) Electric saw for cutting large size angles, tubes and bars.

(iv) Hydraulic press for different pressing uses.

(v) Stationery drill for boring different whole sizes.

H. Welding Machines

Electric welding machines and diesel ones are available**.**

I. Other Equipment

The workshop has a three tons forklift, one small overhead crane, one tractor and three trucks. The following table includes the moving equipments being used in the factory farm at present:-

Table 3.1 Number of Agricultural Machinery and Tractor Used on Gunied Sugar Factory

No	Machine (Make – Type – Power)	Qty.	Purpose used for
1	Wheel tractors 120 Hp.John deer 7710 B 6490C 12206	42	Cane haulage Ridging Hilling up
2	Wheel Tractors 180 Hp.A 200 T A 235 B C 1886	18	HarrowingShunting Ditch opening
3	Wheel Tractor 70 Hp. B 220	40	Herbicide application General purpose
4	Wheel Tractor 250 Hp.A 405 B	3	Land leveling
5	Motor grader 200 Hp. Cat 14 H Cat 12 G Fiat G200	4	Roads
6	Cane harvesters – 275 Hp. Ausoft 700Cane loader	4	harvesting
7	Dozer – 200 Hp.Cat D6D	4	Canalization Bagasse handling
8	Exactors 200 Hp. Komatsu 220 Cat 22 Rb	1 1	Canal maintenance & desalting & weeding
9	Track tyre Tractors 250 – 300 Hp.	4	Land preparation
10	Cane trailers 7.5 tons BlumheartMediema	140	Cane transport
11	Cane loader 100 Hp. A Grap loader	10	Loading of cut cane

Source: Sudanese Sugar Company, Annual Report, 2003

3.3 Data collection:

For the purpose of studying and analyzing sugarcane harvesters failures, maintenance recorded data were identified as paramount. These required data are as follows:

1. The number of failures of harvesters (sample) parts during operation season.
2. Total number of harvesters operating time(hours) and the downtime for repair.

3. The type of failure (partial or combined or complete). Usually partial failure has short downtime while combined and complete has long downtime.

To collect the above mentioned information data,onesugar cane harvester has been selectedfrom each factory for two seasons, data obtained from workshop headquarter and minor workshop of blocks of two factories farms.

Before collecting the final data, a small sample data from two harvesters of each type was taken. This preparatory exercise was made to test the quality of data to be collected and to visualize and evaluate the generated result.

For the purpose of operating the design and functional characteristics of the failure analysis model a list of all data parameters from maintenance record was classified and transformed to satisfy the requirement of running the computer maintenance management model. This includes counting of the cumulative failure frequency, definition of the type of failure and calculated downtime of repair failure. Table 3.2 to Table 3.3 shows the set of complete and satisfied data

Month	Harvester 1			Harvester 2		
	Working Hours	Av No of failure	Repair Downtime (hrs)	Working Hours	Av No of failure	Repair Downtime (hrs)
Jan.	416	20	3.177	416	20	3.156
Feb.	424	18	2.443	416	21	3.17
Mar.	424	17	2.532	424	18	2.38
Apr.	424	19	2.609	468	22	1.806
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
Aug.	0	0	0	0	0	0
Sept.	0	0	0	0	0	0
Oct.	0	0	0	0	0	0
Nov.	468	16	1.45	468	16	1.43
Dec	429	17	2.7	424	17	2.357
Month	**Harvester 1**			**Harvester 2**		
	Working Hours	Av No of failure	Repair Downtime (hrs)	Working Hours	Av No of failure	Repair Downtime (hrs)
Jan.	468	18	1.709	468	18	1.790
Feb.	496	17	1.444	486	15	1.464
Mar.	468	16	1.46	452	22	2.1
Apr.	424	19	2.403	424	23	2.334
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
Aug.	0	0	0	0	0	0
Sept.	0	0	0	0	0	0
Oct.	0	0	0	0	0	0
Nov	486	18	1.82	426	19	2.12
Dec	469	20	1	468	17	1.623

Table 3.2: Data collection from Guniedfactories of Season one and season two

Month	Harvester 1			Harvester 2		
	Working Hours	Av No of failure	Repair Downtime (hrs)	Working Hours	Av No of failure	Repair Downtime (hrs)
Jan.	441	17	1.84	468	19	1.236
Feb.	367	14	1.38	426	18	1.27
Mar.	298	11	1.74	395	16	1.67
Apr.	405	15	1.74	412	15	1.51
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
Aug.	0	0	0	0	0	0
Sept.	0	0	0	0	0	0
Oct.	0	0	0	0	0	0
Nov.	339	15	1.12	444	17	1.66
Dec	419	16	1.42	468	14	1.2
Month	**Harvester 1**			**Harvester 2**		
	Working Hours	Av No of failure	Repair Downtime (hrs)	Working Hours	Av No of failure	Repair Downtime (hrs)
Jan.	441	18	1.967	426	20	2.46
Feb.	426	15	1.55	444	19	1.786
Mar.	468	16	2.177	426	15	2.7
Apr.	405	13	1.609	468	13	1.65
May	0	0	0	0	0	0
June	0	0	0	0	0	0
July	0	0	0	0	0	0
Aug.	0	0	0	0	0	0
Sept.	0	0	0	0	0	0
Oct.	0	0	0	0	0	0
Nov.	398	22	2.03	412	19	1.57
Dec	436	18	1.73	426	17	2.066

Table 3.3: Data collection from New Halfa factory of Season one and season two

3.4 MODEL DEVELOPMENT

The framework of the model development is presented how the parameters used in Gamma distribution can be estimated based on a description of the technical condition of components and systems of sugar cane harvester. Imperfect periodic inspection can be modeled by the proposed approach. The length of the inspection interval depends on the system condition revealed by the previous inspection. The model can be used to compute performance measures over a finite time horizon.

The model of sugar cane harvester failure analysis is a probability model. Failure and maintenance data to run model was collected from the two season's maintenance record of two sugar cane harvester working at Gained and New Halfa sugar cane farms.

Usually, two methods are used for reliability modeling (calculate dependability and availability indicators). The first is mathematical derivation analysis and second is statistical modeling of failures distribution.

The mathematical model represents a system (mechanical, hydraulic and electric) that can either fail completely or undergo periodic. The failed system is repaired. The system transition diagram is shown in Fig. 4.1 the model is useful to predict system availability, probability of system down for Preventive Maintenance, and probability of system failure.

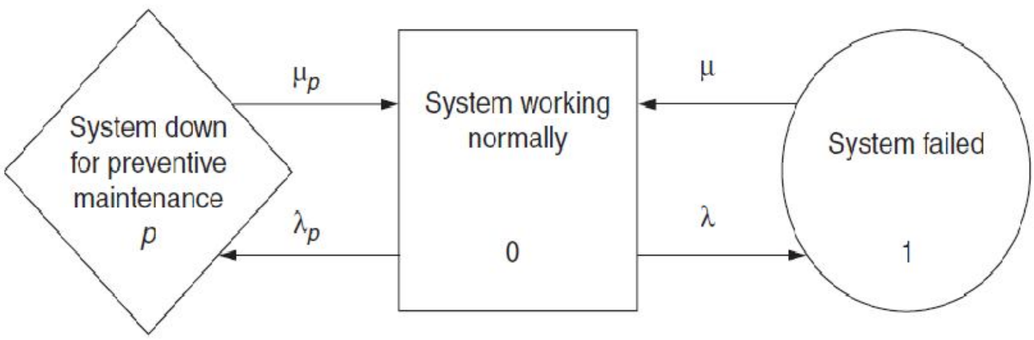


Fig 3.1 System transition diagram

The following assumptions are associated with the model:

1- The component of Sugar cane harvester categorized to mechanical, hydraulic and electric system.
2- Any type of the three systems either in working normally state or failed state with waiting for preventive maintenance as shown in figure 4.1.
3- Preventive maintenancePM , failure, and repair rates are constant.
4- The model assumed that failure of the three systems from state to state can be described as a multi-step process according (**Dalius, (2005)**.
5- After repair or Preventive maintenance , the system is as good as new
6- The following symbols were used to develop equations for the model

j =the jth system state ,j =0(system operating normally),j =1(system failed), j=p(system don for PM),

$p_j(t) = \ probability\ that\ the\ system\ in\ state\ jat\ timet, for\ j = 0,1, p,$

$\lambda = system$ failure rate

$\mu = system\ repair\ rate$

$\lambda_{p} =$ $rate$ of system down for pm

$\mu_{p}= \ reat\ of\ system\ pm\ performance$

The failure analysis model is working with the last two steps given above. It optimizes the service reliability by estimating time for preventive and corrective maintenance and maximum time before failure.

In most reliability reviews, the reason for an increasing failure rate is explained as the effects of wear and tear (deterioration). Therefore, the failure distributions that represent increasing failure rates, such as Weibull and Gamma distributions, are recommended. However, the well-defined failure rate as a function of time is an indication of a deterministic wear propagation (deterioration) process, which is a major limitation of time-based models. The second limitation is the inherent assumption that age can be observed but not deterioration. However, in the majority of cases, measure deterioration can be achieved. For example, deterioration can be a reduction in shaft diameter or impurities in oil analysis.

The model of harvester failure analysis is based on type of failure and operating hours on the field .These two factors, introduced the failure rate (λ). which is defined as the frequency with an engineered system or component, the reciprocal rate of maximum time before failure (MTBF) is more commonly expressed and used for high quality components or systems as given by (**Mishera**, (2006).

Failure rate is usually time dependent, and an intuitive corollary is that change over time versus the expected life cycle of a system. So, the failures occur during the period of system operation can be categorized to the following states:

1. Partial failure state.
2. Combined failure state.
3. Complete failure state.

In partial failure state machine operating at reduced efficiency phase, because the partial failure has no effect on engine or transmission system. Yet by time, without inspection and preventative maintenance action, this fault travel to complete or combined failure. Example of partial failure, on machine system; dirty radiator core, high oil consumption, leakage in one of hydraulic hoses, loose on one of electric cable and defective fan belts.

Combined failure may contain two types of partial failures effected directly, or may contain partial failure causing another to fail with minimum time before failures; this type of failure is a common one, for example, when fuel filter is dirty, it causes clogged fuel line so engine is hard to start or will not start; also if hand control valve is faulty with excessive air leak in air line parking brake, is not releasing.

The complete failure results when machine operation goes off directly, so to shift machine to operation state corrective maintenance and preventive maintenance must be applied. Example of complete failure machine breaks down due to defective on piston rings.

Failure transition rate start from operation state to type of failure state, while repair transition rate start from failure state to operation state. The repair transitions rates include:

1. Inspection and preventive maintenance on partial failure state.
2. Both preventive and corrective maintenance on combined failure state.
3. Corrective maintenance followed by preventive maintenance on complete

Failure state.

3.5 Mathematical Derivation of the Model:

The mathematical formulas of the model normal operation for three states of failure can be written as:

-*System on Working State (S_1)*

The mathematical formula of this state is:

$_1 = \sum_{i=1}^{n-1} \lambda . t . dti \in r \lambda \leq t \geq 0$ ------------------------------ (3.1)

Where

λ = Failure rate,

λ_i^A = failure transition rate before operation state (n) and failure state (i),

t = duration of failure.

- *System on Partial Failure State ($S_{2.1}$, $S_{2.2}$)*

Mathematically this state can be written as:

$$\underset{2.1}{S}(t) = \sum_{i=1}^{i=n-1} \lambda_{s_{21}}^{s_1} \cdot (t) \; t_A \leq t \geq t_{a_1}$$ ---------------------------------(3.2)

$$\underset{2.2}{S}(t) = \sum_{i=1}^{i=n-1} \lambda_{s_{22}}^{s_1} \cdot (t) \; t_A \leq t \geq t_{e_1}$$ ------------------------------- (3.3)

- *System on Combined Failure State (S_{31}, S_{32})*

Failure rate of the states (**a_1e_2, a_2e_1**) is same is transition but it's different on duration:

$$S_{31}(t) = \sum_{i=1}^{i=n-1} \lambda_{s_{31}}^{s_1} \cdot (t) \; t_A \leq t \geq t_{a_1 e_2}$$ --------------------- (3.4)

$$S_{32}(t) = \sum_{i=1}^{i=n-1} \lambda_{S_{32}}^{s_1} \cdot (t) \; t_A \leq t \geq t_{a_2 e_1}$$ ---------------------- (3.5)

Failure transition rate is the frequency with which system or component fails, failure rate is usually time dependent so to obtain the interval rate:

$$\lambda = S_1, S_{21}, S_{22} \cdots, S_{A_{t+i-1}}, S_{a_{n_t}} \quad \text{--------- (3.6)}$$

Where:

S_1 = First step of transition rate,

S_{21} = Second step of transition rate,

S_{22} = Step before last of transition rate (where system is faulty),

$S_{a_{n_t}}$ =Last step of transition rate (where system is failed).

The transition rate of failure can be estimated as (MacDiarmid, et al, 1998.) equation:

$$\lambda_{S_n}^{s_1} = \frac{\text{Number of failure}}{\text{working hours}} \quad \text{---------------------------------- (3.7)}$$

So, the maximum time before state start failure can be calculate by limit integral of sate equation before first step and step before last as:

$$S^{\max}(t) = \int_{S_n}^{S_{1+n-1}} \frac{n}{t_h} \cdot dt \quad \text{----------------------- (3.8)}$$

Where:

$S^{\max}$ = maximum time before state start,

n = Number of failure,

S_{1+n-1} = last step before failure,

S_n = First step of system operation,

t_h = Working hours.

Moreover, we have:

$$S^{\max}(t) = \left[n \cdot \ln(t)\right]_{S_n}^{S_{1+n-1}} \text{ ------------------------------ (3.9)}$$

By solving equation for n, we obtain the maximum time before fault (time to inspection and made Preventive maintenance)

$$S^{\max}(t) = (n \cdot \ln(t+n-1)) - (n \cdot \ln(t)) \text{ -------------------- (3.10)}$$

$$S^{\max}(t) = n \cdot \left[\ln\left(\frac{t+n-1}{t}\right)\right] \text{ ------------------------------------ (3.11)}$$

The probability of step before failure (t+n-1) estimation by Gamma distributions which is discussed later, and by applying equation (3.11) to all failure states we obtain:

- *systemon Partial Failure State (S_1, S_{11})*

$$S^{1_{\max}}(t) = n \cdot \left[\ln\left(\frac{s_{1_{t+i-1}}}{s_t}\right)\right] \text{ ------------------------------------- (3.12)}$$

$$S^{11_{\max}}(t) = n \cdot \left[\ln\left(\frac{s_{1_{t+i-1}}}{s_{11}}\right)\right] \text{ ------------------------------------ (3.13)}$$

- *system on Complete Failure State (S_{12}, S_{22})*

$$S^{12}(t) = n \cdot \left[\ln\left(\frac{s_{12+i-1}}{S_{12}}\right)\right] \text{ -------------------------------------- (3.14)}$$

$$S^{22}(t) = n \cdot \left[\ln\left(\frac{s_{2\,2+i-1}}{S_{22}} \right) \right] \text{ --------------------------------------- (3.15)}$$

The state of machine operation represent as probability transition rate of Gamma distributions which can be defined by the following equation:

$$f_R(t) = \left| \frac{\lambda^{\beta}}{\Gamma(\beta)} \cdot t^{t^{\beta-1}} \cdot e^{-\lambda t} \right| \text{ --- (3.16)}$$

The application of equation 4.16 to all system can be summarized as:

-Partial failure state:

$$f_R(t) = \left| n \cdot \left[\ln\left(\frac{1-\lambda_{s_1}^{\beta}}{\lambda_{s_{11}}} \right) \cdot t^{t^{\beta-1}} \cdot e^{-\lambda_{s1} t} \right] \right| \text{ --------------------- (3.17)}$$

-Complete failure state:

$$f_R(t) = \left| n \cdot \left[\ln\left(\frac{1-\lambda_{s_1}^{\beta}}{\lambda_{s_{12}}} \right) \cdot t^{t^{\beta-1}} \cdot e^{-\lambda_{s2} t} \right] \right| \text{ --------------------- (3.18)}$$

-Combined failure state:

$$f_R(t) = \left| n \cdot \left[\ln\left(\frac{1-\lambda_{21}^{\beta}}{\lambda_{s22}} \right) \cdot t^{t^{\beta-1}} \cdot e^{-\lambda_{s2} t} \right] \right| \text{ ------------------------ (3.19)}$$

3.6 Model Outputs:

The outputs of model include:

1. Failure and Repair Rate:

The failure and Repair Rate is the first outputs of cane harvester failure analysis model, it estimate by applying the set of probability equations for transition rate before all passable states, for one cycle operation life of system. The equation of Gamma distribution probability transition rate can be transferred to maintenance information by estimating failure analysis and failure frequency as shown on the following table

Table 3. 4 Availability Transition Rate of Failure and Repair

Preventive and Corrective Maintenance Duration	
Mean of Preventive Maintenance (PM)	Inverse of frequency of S_{11} to S_1
Mean of Corrective Maintenance (CM)	Inverse of frequency of S_{12} to S_1
Mean of Preventive and Corrective Maintenance	Inverse of frequency of S_{22} to S_1
Total Number of PM	Summation of Mean of PM
Total Number of CM	Summation of Mean of CM

2. Prediction of maintenance policy :

This outputs describe the forecasting of failure behavior for the next time according to last operating hours and number of failure during this time, its includes:

1) Maximum time before failure(MTBF) ; which can be calculated as follow :

$$MTBF = \left| n \cdot \left[\frac{\ln\left(1 - f_R(t)\right)}{S_1} \right] \right| \text{----------------------------------- (3.20)}$$

Where:

$f_R(t)$ = System Probability from Gamma calculate

This time can be shown graphically through the three states of failure. The graph can be helpful tools to the decision maker to know which type of system recorded high time before failure and link that with filed operation condition.

2) System availability:

Availability prediction and assessment methods can provide quantitative performance measures that may be used in assessing a given design or to compare system alternatives to reduce life cycle costs. This technique increases the probability of mission success by ensuring operational readiness. Analyses based on availability predictions will help assess design options and can lead to definition of maintenance support concepts that will increase future system availability; anticipate logistics and maintenance resource needs.

The typical objectives of availability testing are to determine:

a. If the application meets its operational availability requirements. (For example, availability testing can cause failures due to oil leaks or fuel system defects.)

b. How stable the operating time of system is, whether (and how much) downtime is required for maintenance purposes, it is calculated as:

$$SV = \sum_{i=1}^{n} \lambda_i^{S_1} \text{ --- (65)}$$

3) System Dependability:

By using MTBF the system dependability which is obviously a desirable system attributes and even if a system is designed to be "dependable," it is likely that it will need maintenance at some point in its life; SD can be obtained from the equation:

$$\frac{\text{MTBF}}{(\text{MTBF} + \text{MTTR})} \cdot 100 \text{ ------------------------------ (66)}$$

Where:

MTTR = Maximum Time to Repair

4) Operating time before PM and CP:

This term is illustrated from Gamma distribution probability outputs namely model probability. It is calculated as transition probabilities of all states (partial combine and complete). The following equation is used to calculate CM:

$$CM = \frac{\sum_{i=1} t_i}{\sum_{i=1} CM_i} \text{ --- } (67)$$

Where :

t_i = Duration of operating during specific states (probability transition state)

CM = Preventive maintenance on state i

Preventive maintenance calculates by the same equation but at different probability transition state.

Operating time before PM and CP is indicator tools for how downtime can be reduced as percentage of probability transition before states if using optimal predict of maintenance policies.

3.7 Model Selection:

Figure 3.2 shows the flow chart of failure analysis model. The selection of model is based on understanding the failure behavior of the repairable system , by providing a mathematical equation to optimize the preventive and corrective maintenance and forecast future failures through the formulated mathematical model also to optimize the maintenance strategy for the repairable system by analyzing the relevant information. From the stochastic point of view of the process it is also important to determine the process failure trend, to know whether a failure rate is increasing, decreasing or constant. One of the most important decisions that a maintenance manager must take comprises the timing of system/equipment replacement. This is to be done to balance optimally before the frequencies of maintenance against the expected failure.

Various failures were identified and categorized as mechanical to complete, combined and partial.

After the model is formulated and its parameters estimated, it can be used to predict the expected number of failure (number of CM) by sorting equation data in the Microsoft Excel operating environment to build tables of failure times and inter-failure times and availability based on user – defined selection of data from the model database, Moreover Appendix (1) show the spreadsheet code equation of failure analysis.

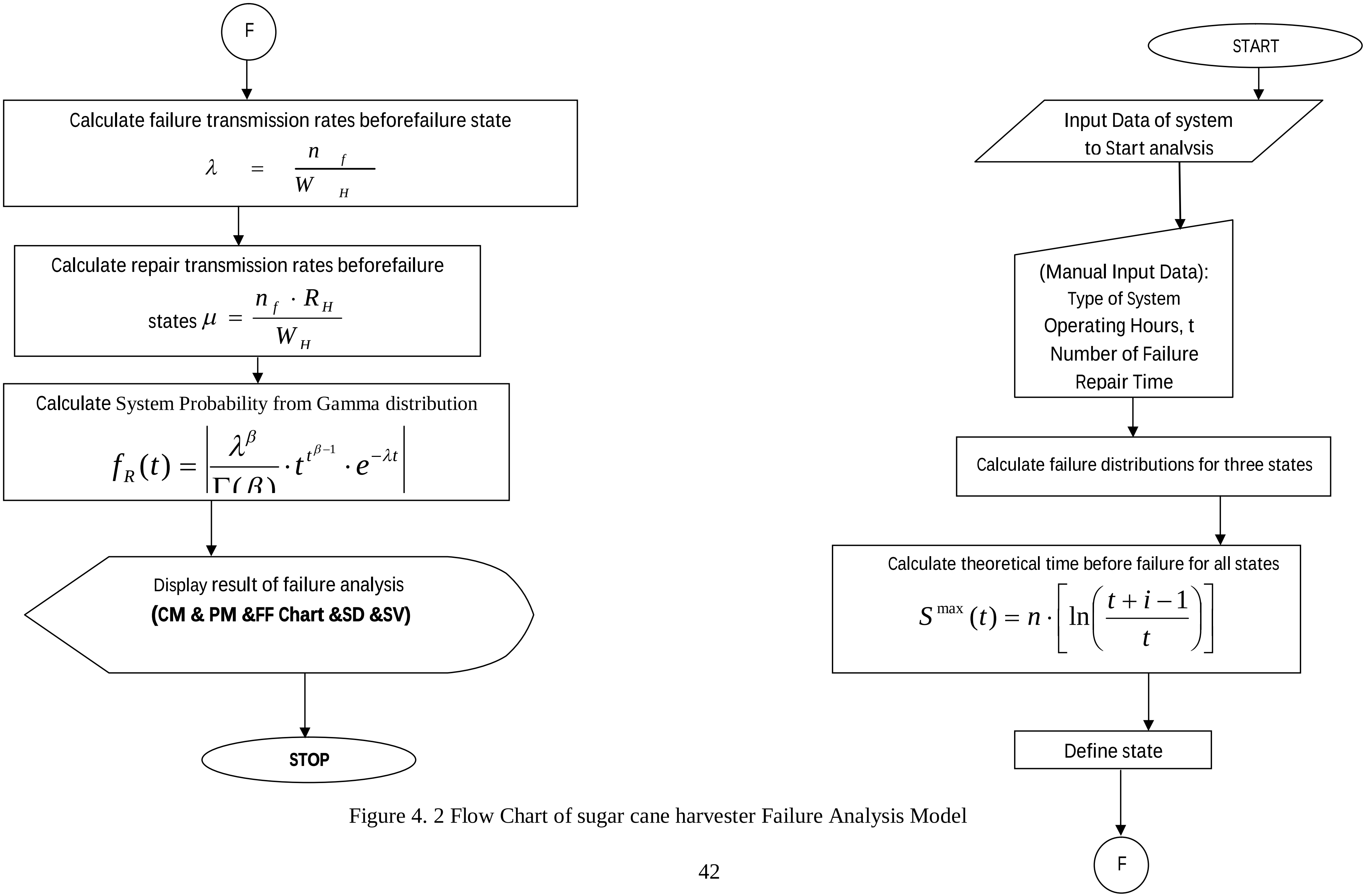


Figure 4. 2 Flow Chart of sugar cane harvester Failure Analysis Model

CHAPTER FOUR

RESULTS &DISCUSSION

4.1 Model validation:

The failure analysis model for management of sugarcane harvester maintenance is validated by comparing performance of the main output of the model (the average number of failure), with that recorded in Gunied Sugar Factory.

As outlined in chapter three, data of two seasons of sample sugarcane harvesters, operating in New Halfa and Gunied factories was used as input data (Table 3.1, Table 3.2) for purpose of generate and predict expected average number of failure. As depicted in Table 4.1 and 4.2 the model results is compared to actual workshop data for the same sugarcane harvesters in the same workshop. However, in practice it is difficult to achieve a full validation of the model by running a complete failure analysis (by testing: maximum time before failure (hours), operating time before Preventive Maintenance, operating time before Corrective Maintenance, and average of frequency) due to measurement problem and data availability and accuracy. For this reason initial validation attempts will concentrate on the main output of the model (the average number of failure), and only if that validation suggests a problem will more detailed validation be undertaken.

Table 4.3 indicate that there is no significant difference (at P= 0.05) before the average number of failure predicted by the model and that recorded in Gunied Sugar Factory.

Table 4. 1 Maintenance Data of sugarcane Harvester in Gunied factory of Season one

Harvester 1			
Month	Working Hours	Av No of failure	Repair Downtime (hrs)
Jan.	17.92	3	1.84
Feb.	18.56	2	1.38
Mar.	17.97	2	1.74
Apr.	18.16	2	1.74
May	0	0	0
June	0	0	0
July	0	0	0
Aug.	0	0	0
Sept.	0	0	0
Oct.	0	0	0
Nov.	18.81	2	1.12
Dec	18.51	3	1.42

Table 4. 2 Model Results Compared to Actual Workshop Record Data

Machine 1		
Month	Number of failure (First Season) from workshop record	Average Number of failure (Predicted by the model from Second Season)
Jan.	17	13
Feb.	14	9
Mar.	11	13
Apr.	15	12
May	0	0
June	0	0
July	0	0
Aug.	0	0
Sept.	0	0
Oct.	0	0
Nov.	15	17
Dec	16	14

Table 4. 3Statistical Analysis of Average Number of Failure

Source	Mean	Std. Deviation	Std. Error Mean	df	Sig. (2-tailed)
Av No of failure (first season) Av No of failure (second season)	2.387	5.321	1.521	11	0.030

*The mean difference is significant at the .05 level

4.2Model application:

The failure analysis maintenance management model is run using two sugarcane Harvesters data, collected from two study sites, Guneid factory workshop and New Halfa factory workshop. The purpose is to investigate and evaluate performance of the studied Harvesters in these two workshops using three proxy indicators (maximum time before failure (MTBF), system dependability (SD) and system availability (SV).

The failure analysis system model program mainly consists of two sections: menu, for database entering, and outputs screen as shown in Fig. 1. Each section has a number of subsections based on

the design criteria for the program development. The program starts with an opening screen as shown in Fig. 2.

Fig 4.1 the menu of model program for database entering

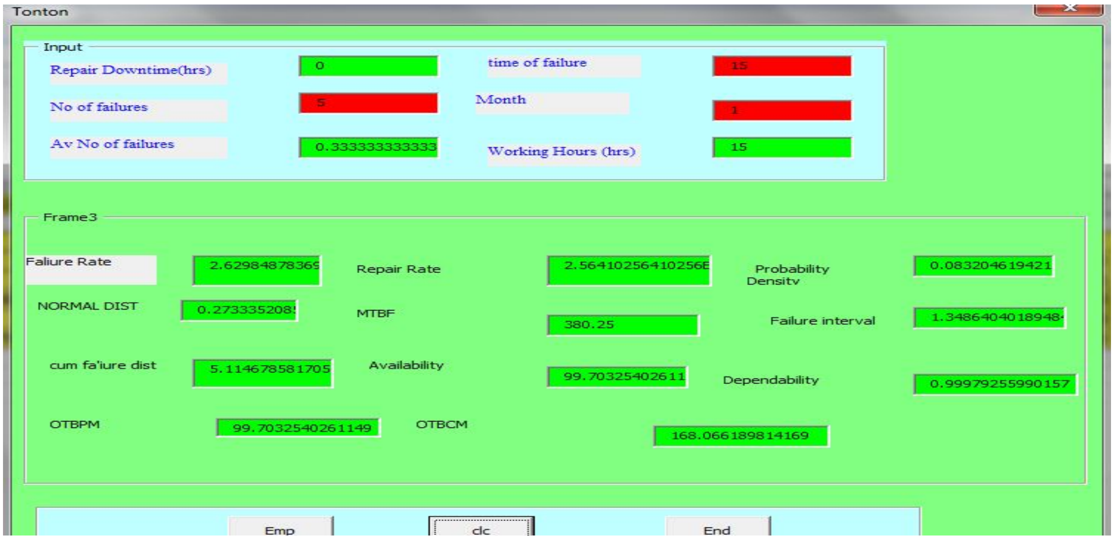


Fig 4.2 model outputs screen

4.3Impact of Dependability on maximum time before failure :

Figure 4.3 shows the dependability as function of the maximum time before failure, the significance of the time before failure 50 % Machine Dependability (MD_{50}) is that it is the time before failure at which a system has a 50 - 50 chance of failure. From figure 4.3, it can be deduced that the harvester of Sinnar is the most dependable with a 50 % dependability of 12 hours of time before failures. The least dependable is that of harvester of Guneid with a 50 % dependability of 98 hours of time before failures. While harvester of Guneid showed at 50 % dependability a value of 14 hours of time before failures.

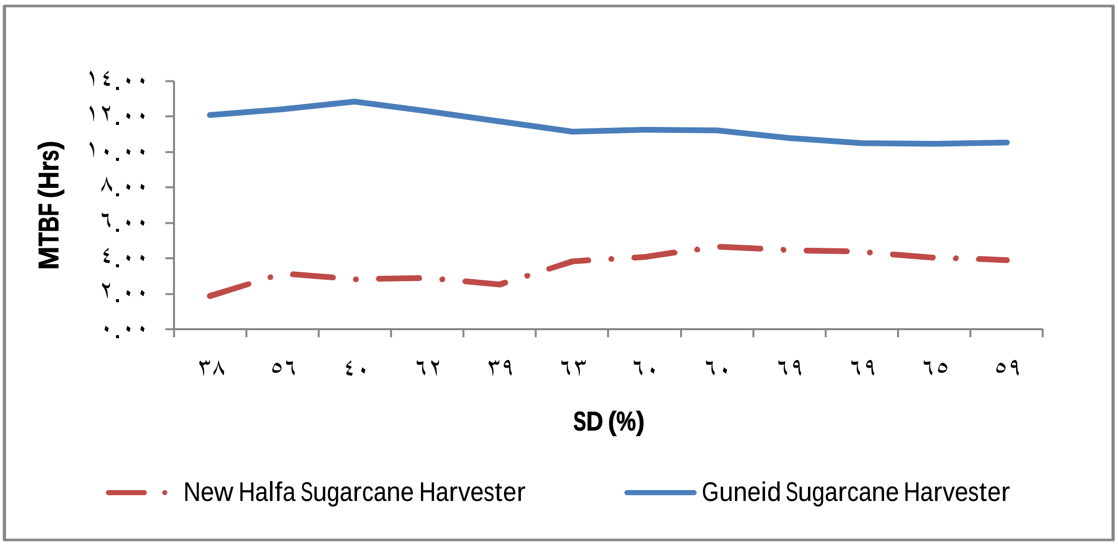


Fig 4.3 Impact of Dependability on maximum time before failure

4.4Impact of Availability on maximum time before failure:

The availability response curve for the two Harvesters with significant impacts on maximum time before failure as estimated in step one above is depicted in figure 4.4 The significance of the time before failure 50 % Availability (AV_{50}) is that it is the time before failure at which a system has a 50 - 50 chance of failure. Figure4.4, indicate that the A Harvester of Guneid is the most reliable with a 60 % Availability of 12 hours of time before failures. The least reliable is that of Harvester of Guneid with a 50 % dependability of 10 hours of time before failures. While Harvester of Sinnar showed at 92 % Availability a value of 14 hours of time before failures.

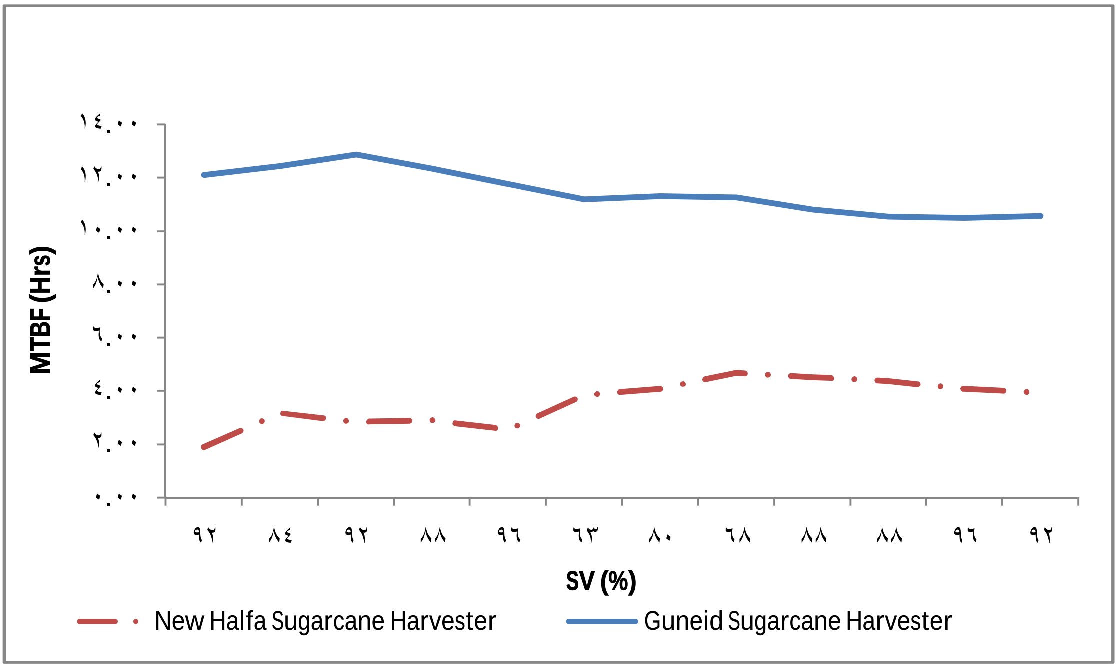


Figure 4. 4 Impact of Availability on maximum time before failure

4.5 Performance of existing maintenance system:

The main indicators used in this study to evaluate level of performance of actually executed maintenance and the need of the studied Harvesters for either preventive or corrective maintenance is planned to be made by evaluating three parameters: maximum time before failure, Harvester dependability, and Harvester availability. These parameters are selected in accordance with Desai *et al*, (2006). The selection of the said parameter is oriented to be in line with quantitative outputs that can be generated as model outputs and reflect model behavior, and more important the system used for Harvesters maintenance in the Sudanese Sugar Company. As will be detailed latter in this discussion there is strong interlink before the selected performance parameters, the type of maintenance to follow (corrective or preventive) and management of maintenance in relation to Harvesters use in the field. Consequently, these indicators are viewed as abstract representation of the existing system.

4.5.1 Analysis according to maximum time before failure:

The sequence of seasonal mechanized operations (tillage to harvest) for Sugar factories as given in the chart of figure 3.4 starts by October and the operations grows gradually through months of November, December, January February, March, April to end in May. The period from start of June to end of September is characterized with the lowest level intensity of mechanized field operations and is normally considered as the optimum period for corrective Harvester maintenance. While preventive maintenance is normally planned to cope with the time of maximum intensity of field work (Done usually at weekends and at emergency need). The philosophy behind this is to increase Harvester availability for field work and thus increase frequency of sudden breakdown

It is usually assumed that the required maintenance level is reflected in Harvester maximum time before failure (available time free of defects) occurs. For improving level of mechanized field operation it favorable to have less Harvester downtime and long working period at time of Harvester peak demand.

Harvester 1:

The period from July to month October is the lowest time before failure .Figure 4.5 shows that the maximum time before failure is 2 hour and coincide with the period of peak frequency failure(Vide: figure 4.5) .In contrast July is the month of the lowest operating time before corrective maintenance (15 hours) .It is evident from the figure 4.5 that in this same month (July) corrective maintenance started to improve and the 999time start slowly creeping from 2 hour to approximately 6 hours on average. On the other hand the Preventive maintenance sequence has same trend but with very slowly creeping as shown on figure 4.5 (from 2 to 6 hours) as daily Preventive maintenance.

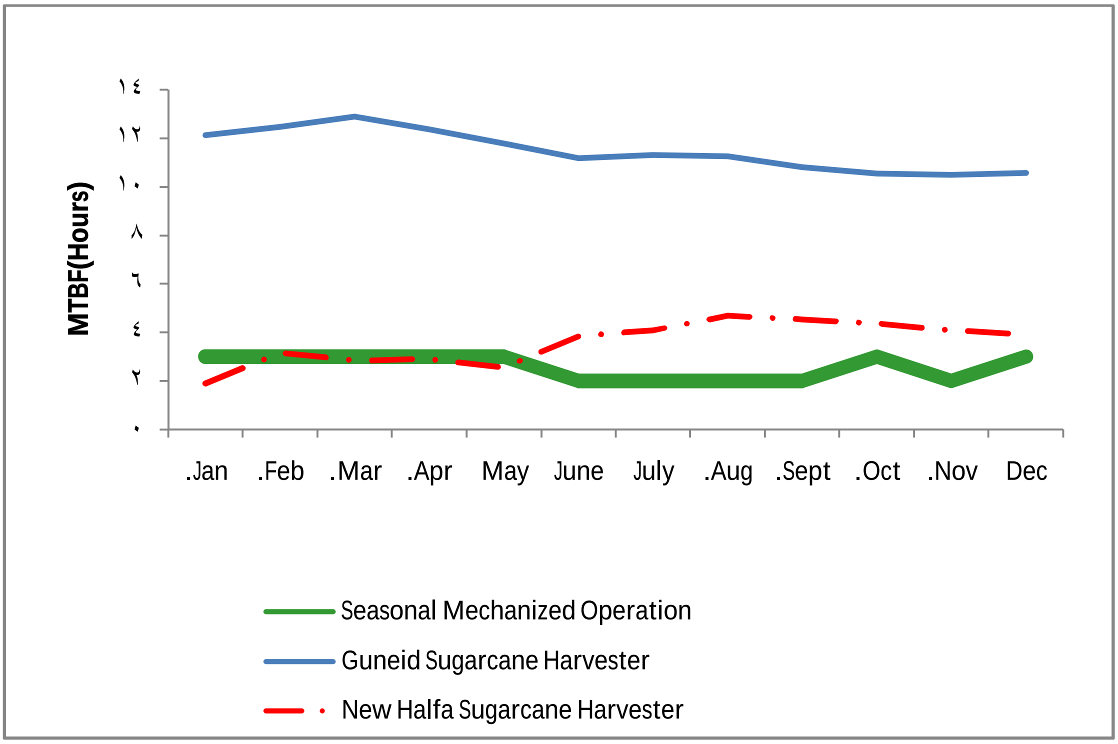


Fig 4.5 Impact of Availability and maximum time before failure (Harvester 1).

Harvester 2:

As given in figure 4.6 the maximum time before failure of this Harvester is 12 hour at time of start of heavy field operations for crop harvesting (March) and it continues with slight decrease to a value of 10 hours in November which lies within the time of heavy work load. In the period from February to November the maximum time before failure is almost constant at a value of 11 hours. In actual practice as seen in figure 4.6 the period of month May and June is the period for corrective maintenance where the operating time bet CM actually increases from 40 hours by May to 50 hours in June and then drop down to 20 hours by July. Recall that this is the period of least field work and maximum maintenance work load.

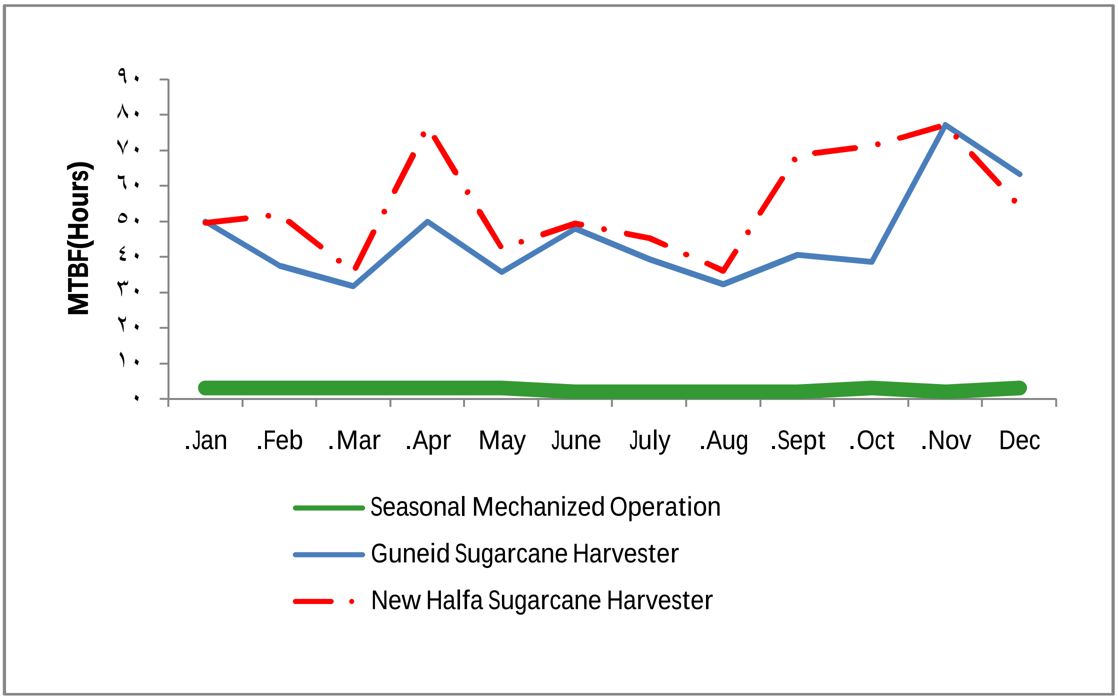


Fig 4.6 Impact of Availability and maximum time before failure (Harvester 2).

4.5.2 Analysis according to failure rate:

*For Harvester 1:*Figure 5.7 shows two peaks of maximum frequency of failure (at months of June and August). Months of May, November and December are of lowest field work load and at the same time shows lowest frequency of failure. Hence, failure frequency is linked with heavy field use or misuse. The figure confirm the fact that frequency is decreasing with work decrease in period from June to August and similar trend is followed by both PM and CM. This result is in agreement with the trend line of maximum time before failure given in table5.3 and Figure 5.5for the staid period.

For Harvester 2: The frequency of failure as given Figure 5.7 starts to slightly increase from June to September (The peak is at August). The trend is similar to that of both CM and PM figures except in February to March months where there is high value of failure at time when Harvester is subject to heavy work load. This may refer to inadequate maintenance and to shorten the time before preventive maintenance from 30 hours to a reasonable time (19 hours). Reading figure 5.9 it is possible to deduce that: the frequency of failure in general is in contrast to the maximum time before failure.

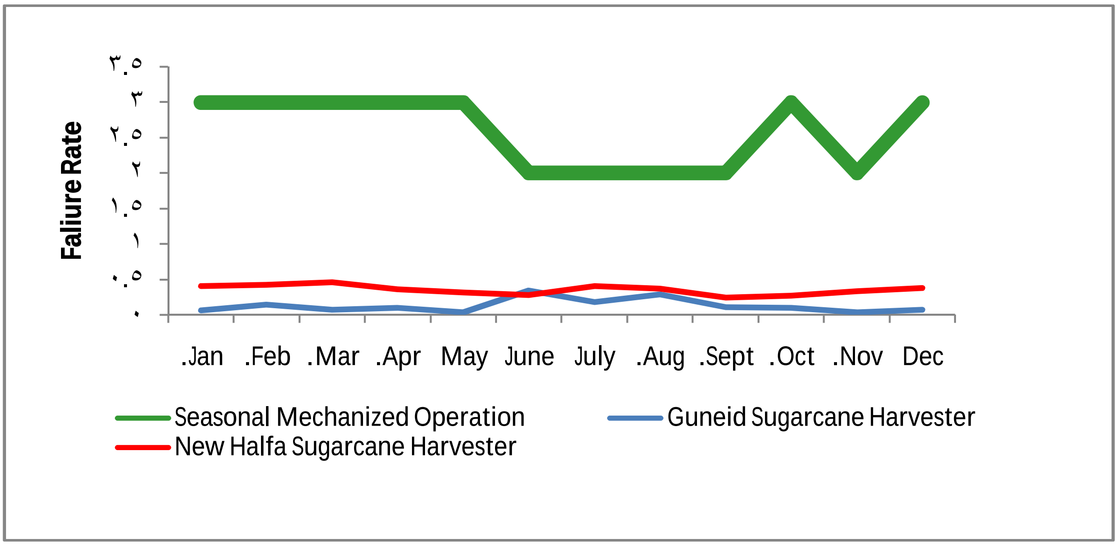


Figure 5. 7 Average of Failure Rate of Harvester for Guneid and New halfar Factory

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1conclusions

The developed failure analysis model for management of Harvester maintenance is formulated on sound knowledge base and capable enough to predict actual number of failure. These are made firstly by analytical approach to verify the model internal theoretical structure (probability transition matrix between states and subsets) in comparison to Amari, McLaughlin model (2004). Secondly by validating model powers to predict number of failure in relation to actual ones recorded in the field, using Macal, (2005) procedure.

Analysis of performance of two Harvesters and level of maintenance in two workshops with respect to MTBF, MD, AV, OTBPM, and OTBCM.

Evaluation of maintenance quality with respect to maximum time before failure, dependability and frequency of failure is qualified and detailed in the text for each Harvester type.

The improvement of Harvester field scheduling programmme through the combined effects of Harvester reliability and time lines (Harvester availability) is based on the assumption that past historical behavior the highly to occur in future under similar Harvester management condition. Harvester availability is found to be around 50% and the reliable number of Harvester needed to execute field operation time of peak demand in Sudanese company sugar cane farms in 58 Harvesters in steady of using the current risky number with unpredicted failure of 38 Harvesters. Availability factor of 0.9 is recommended adjusting number of Harvester needed to exact farm operation.

Instead of using the static Harvester maintenance scheduling performance recommended under ideal design conditions, the failure model predicate alternative dynamic and more real maintenance policy scheduling programmme.

5.2 . Recommendations

1. The validated and verified model developed in this study is recommended to be employed for Harvester failure analysis and for selecting maintenance policy.
2. Selection of suitable Harvester type needs to be made in relation to available quality of maintenance (Workshop capabilities).
3. The model can be used to estimate Harvester availability factor, for adjusting scheduling programmme for executing mechanized cultural operation.
4. Analysis of the model may be extended in future to include additional subroutines for each individual subsystem of the Harvester (fuel, lubrication, electrical…etc).
5. The developed model may be used for analysis of Harvester in the case of un predictable Harvester working days of rainfed farming system.
6. To develop effective Harvester management system and sound maintenance policies it is essential to give more emphasis to improve record keeping system and Harvesters log-book using computer facilities.

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