Major causes of failure during harvesting in sugarcane chopper harvester machine

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Abstract: Evaluation of maintenance strategies is an issue which must widely be considered. This paper describes failure rate, mean time between failures (MTBF) and availability analysis for Austoft 7000 sugarcane harvesters series used in agro-industries in southwestern Iran. Sugarcane harvester was divided into three subsystems and the failures were studied for 1800 working hours. The failure rate of subsystems including hydraulic, mechanical and electrical were calculated 0.087, 0.052 and 0.012 h-1, respectively and the total failure rate was 0.15 h-1. MTBF after 1800 working hours were obtained 11.46 h, 19.35 h and 85.71 h for the aforementioned subsystems and machine MTBF was 6.64 h. Among the three studied subsystems, hydraulic with maximum failure rate and minimum MTBF and electrical subsystem with minimum failure rate and maximum MTBF were recognized as the most unreliable and reliable subsystems respectively. Moreover, availability analysis showed availability for hydraulic, mechanical and electrical subsystems were 85%, 90% and 98%, respectively. However, total machine availability was 76%.

Keywords: availability, failure rate, MTBF, sugarcane harvester

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1 Introduction

The ‘failure’ is the manifestation of an ‘error’ which follows a ‘fault’. In the literature, these faults are generally considered as being of systemic origin, resulting from the phenomena of wear, fatigue, infant mortality or can be purely random (Peres and Noyes, 2003).

The life of a population of units can be divided into three distinct periods. Figure 1 shows the reliability “bathtub curve” which models the cradle to grave instantaneous failure rates *vs*. time. If we follow the slope from the start to where it begins to flatten out this can be considered the first period. The first period is characterized by a decreasing failure rate. It is what occurs during the early life of a population of units. The weaker units die off leaving a population that is more rigorous. This first period is also called infant mortality period. The next period is the flat portion of the graph. It is called the normal life. Failures occur more in a random sequence during this time. It is difficult to predict which failure mode will manifest, but the rate of failures is predictable. Notice the constant slope. The third period begins at the point where the slope begins to increase and extends to the end of the graph. This is what happens when units become old and begin to fail at an increasing rate (Barabadi and Kumar, 2007; Kumar and Klefsjo, 1992; Kumar et al, 1989).

One of the most important factors to reach the highest crop yield due to the lowest loss is operating on time. In order to machine scheduling we should aware from its efficiency. It is impossible without exact information about status of different machine’s parts. Availability is possibility of corrective system performance in the future (Najafi et al, 2015). There are six different methods to

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availability computing, including: instantaneous availability, average uptime availability, steady state availability, mechanical availability, achieved availability and operational availability. Mechanical availability is the best method to finding machine availability (Hoseinie et al, 2012; Barabadi and Kumar, 2008).

Whereas 60 % of global sugar production reaches from sugarcane (Bagherzadeh, 2009), this crop plays a key role in sugar production industries. Sugarcane harvesting usually accomplishes in two methods consist of hand harvesting and mechanization harvesting, but mechanization harvesting is more generalized in Iran. In order to mechanization cane harvesting use of sugarcane chopper harvester is conventional (Figure 2).

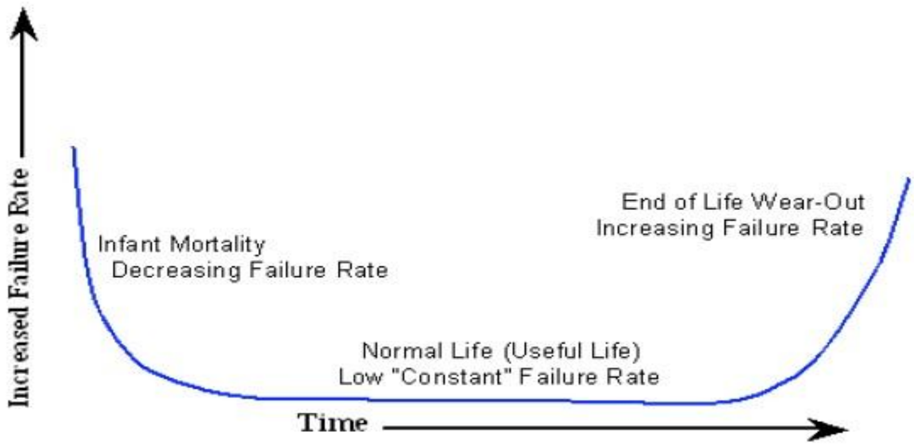
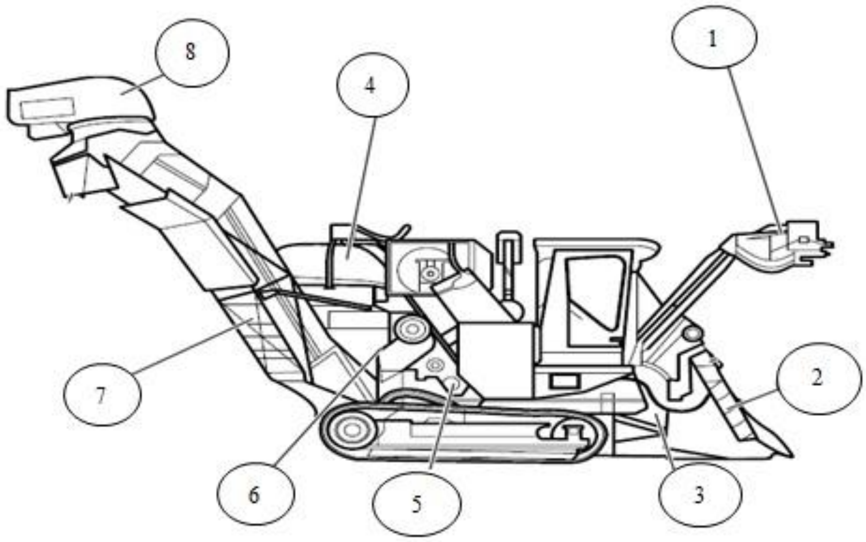


Figure1 Reliability bathtub curve



1-Topper 2- Crop dividers 3- Base cutter 4- Primary extractor fan 5- Feed rollers 6- Chopper 7- Elevator 8- Secondary extractor fan

Figure 2 Austaft sugarcane harvester and its important components

The main objectives of the case study in this paper are:

- To increase understanding of the nature of the failure patterns of the sugarcane chopper harvester;
- To estimate the reliability and availability characteristics of the sugarcane chopper harvester in precise quantitative terms;
- To identify the critical subsystems of the sugarcane chopper harvester, which require further improvement through effective maintenance policies to enhance the operational reliability and availability, prevent faults and formulate a reliability-based maintenance policy.

2 Materials and methods

Study area , Hakim Farabi agro-industry Company, was located in 35 km south of Ahvaz in Iran. Arable lands of this company are located in 31 °0 N to 31 °10 N latitude and 45 °0 E to 48 °36 E longitudes. This region has dry and warm climate. Soil of this region is heavy and semi-heavy and each farm size is 25 ha in regular forms. Totally, 24 Austoft 7000 sugarcane harvester are being used in the company. The machines were between 8-10 years old. The failures can occur mechanically, hydraulically or electrically, (Figure 3).

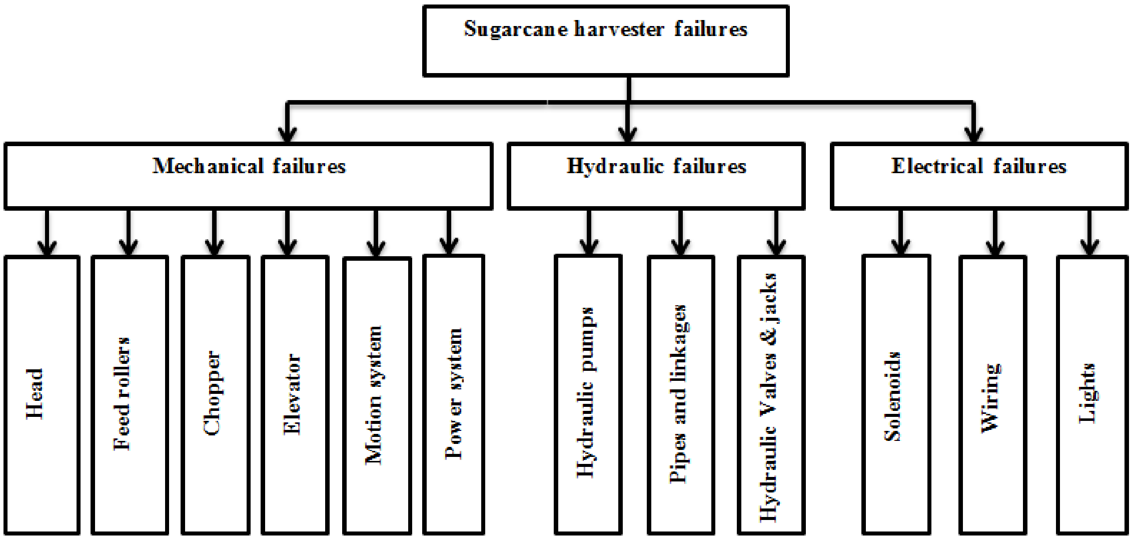


Figure 3 Sugarcane harvester failure classification

Sugarcane harvester is a hydraulically machine. The pump is the heart of a hydraulic machine. Since, the pump converts the mechanical power received from the mechanical power source into the hydraulic power in the form of pressurized fluid at its outlet port. Here, the mechanical power source is an internal combustion engine so-called power system. The pumps used in the structure of cane harvester are radial piston pump that built on a rotating shaft with the cylinder block rotating on the outside. As the piston follows the outlet housing of the pump on slippers, the offset from the central position creates the pumping motion. The internal combustion engine is Cummins QSM11-330 (Table 1).

Table 1 Specification of Cummins QSM11-330 engine

Parameters	Value
Number of cylinders	6
Firing order	1,5,3,6,2,4
Horse power	330 HP @ 2100 r/min
Capacity	10.8L
High idle	2200 r/min
Low idle	675-750 r/min
Oil capacity	38 L
Water capacity	54 L total system capacity
Stroke	147 mm

Another failure source at cane harvester is feed rollers. Roller feed train, feeds the cut cane, but first to the choppers and allows the trash and dirt to fall clear. The feed roller train consists of a butt roller directly behind the base cutter end five lower fixed roller end five floating upper roller.

Elevator conveys the cut cane to the bin and allows dirt to fall clear. The slew is controlled by operator. The elevator slewing mechanism consists of two opposing cylinders attached to the main frame and elevator cradle by pins. The two cylinders operate in a push pull mode and turn the cradle trough 160°. The elevator is a high clearance type to minimize the damage caused by various cane receiving containers coming in contact with the underside of the elevator. The elevator itself is adjustable in height; this is controlled from the cab by way of two hydraulic cylinders supporting the elevator. This allows the elevator to be lowered for traveling in areas of overhead obstructions, and to minimize height of platforms required to work on the extractor and head shaft.

Chopper is the rotating drums fitted with blades chop the cane into billets. The chopping system consists of two contra-rotating drums with machined blades mounted to both drums. The drums are hydraulically driven by two individual motors and are synchronized by timing gears. A flywheel running on a separate shaft driven by the top timing gear gives added inertia to balance the system.

Data are from maintenance reports of nine cane chopper harvester which have been recorded within 1800 working hours (Table 2). Moreover Figure 4 describes these quantities in the chart form.

Table 2 Statistical summary of sugarcane harvester subsystems failures

Subsystems	Failures number	Failures percentage/%
Hydraulic pumps	47	17.3
Pipe and linkages	86	31.7
Valves and jacks	24	8.9
Power system	11	4.1
Motion system	13	4.8
Head	17	6.3
Feed rollers	21	7.7
Chopper	17	6.3
Elevator	14	5.2
Solenoids	9	3.3
Wiring	8	3.0
Lights	4	1.5
Total	271	100

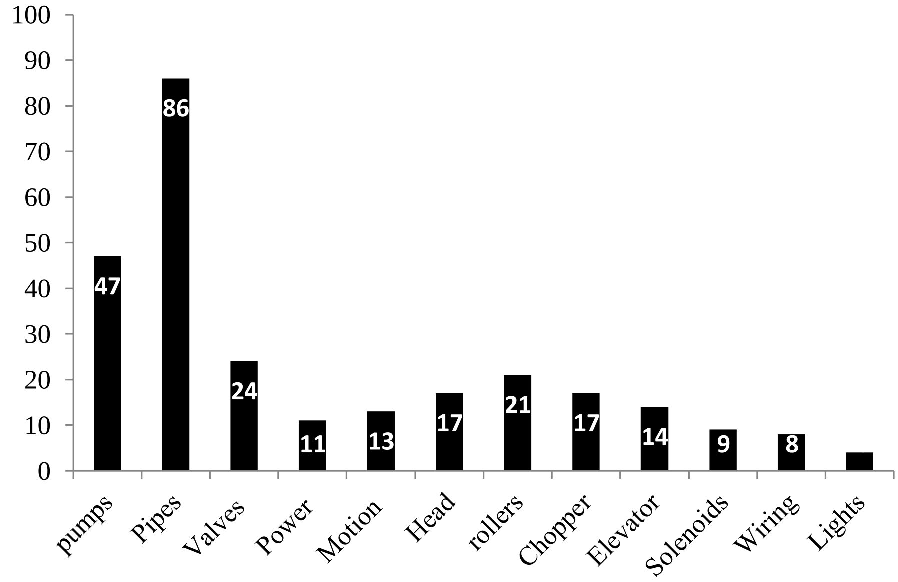


Figure4 Failures number chart of cane chopper harvester components

2.1 Failure rate

Failure rate from Equation (1) is the frequency with which an engineered system or component fails. The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system (Shirmohammadi, 2002).

$$\lambda = \frac{F}{H} \qquad (1)$$

Where λ is failure rate, F is number of failures, and H is operation hours.

2.2 Mean time between failures

Mean time between failures from Equation (2) is the predicted elapsed time between inherent failures of a system during operation ((Billinton and Allan, 1992).

$$MF = \frac{U}{N} \qquad (2)$$

Where MF is mean time between failures (h), U is uptime, and N is number of system failures.

2.3 Mean time to repairs

Mean time to repair from Equation (3) is a basic measure of the maintainability of repairable systems. It represents the average time required to repair a failed component or device. Expressed mathematically, it is the total corrective maintenance (CM) time for failures divided by the total number of corrective maintenance actions for failures during a given period of time (Billinton and Allan, 1992).

$$MR = \frac{C}{T} \quad (3)$$

Where *MR* is mean time to repair (h), *C* is corrective maintenance downtime, and *T* is Total CM actions.

2.4 Mechanical availability

Mechanical availability is the steady state availability when considering only the corrective maintenance downtime of the system. This classification is what is sometimes referred to as the availability as seen by maintenance personnel. This classification excludes preventive maintenance downtime, logistic delays, supply delays and administrative delays. Since these other causes of delay can be minimized or eliminated, an availability value that considers only the corrective downtime is the inherent or intrinsic property of the system. Many times, this is the type of availability that companies use to report the availability of their products, because they see downtime other than actual repair time as out of their control and too unpredictable.

The corrective downtime reflects the efficiency and speed of the maintenance personnel, as well as their expertise and training level. It also reflects characteristics that should be of importance to the engineers who design the system, such as the complexity of necessary repairs, ergonomics factors and whether ease of repair (maintainability) was adequately considered in the design.

The mechanical availability computed from Equation (4), (Hall and Daneshmend, 2010).

$$A = \frac{MF}{MF+MR} \times 100 \quad (4)$$

Where *A* is mechanical availability.

3 Results and discussion

3.1 Pareto chart analysis

For identification of critical subsystem, Pareto analysis (failure frequency analysis) was done on the available data. The result of this analysis is shown in Figure 5. The Pareto chart resulted from an analysis of the high ranking parts and the occurrence rate of failure, and indicates the number of failure occurrences for each part of the total failure occurrence. The most frequent failure occurrence is hydraulic parts (57.93%), the mechanical parts (34.32%) and the electrical parts (7.75%). Therefore, the efforts must be concentrating on decreasing hydraulic failures to more reliable machine performance. According to this result it’s obvious that any improvements or comprehensive maintenance should

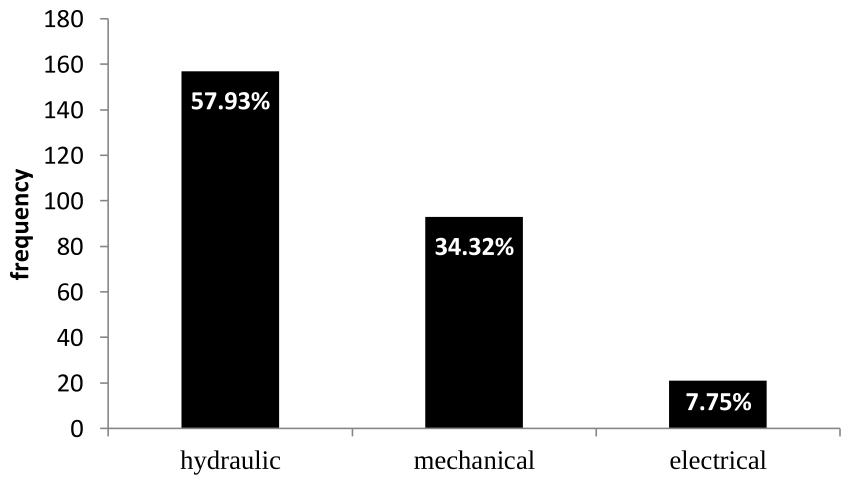


Figure 5 Pareto charts of sugarcane harvester failures

place a high level of attention on these subsystems.

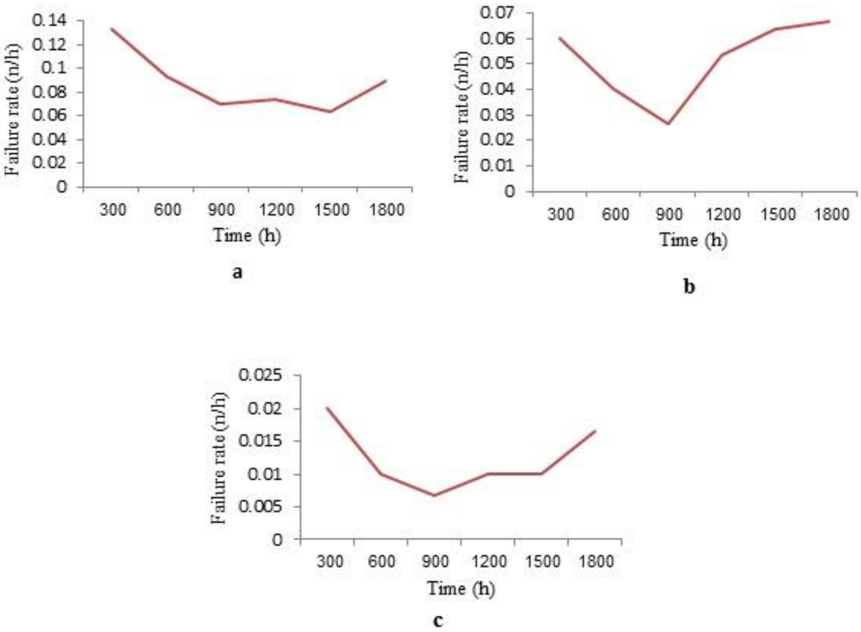
3.2 Failure rate and MTBF analysis

Failure rate analysis was carried out to investigate the failure potential and age condition of defined subsystems. First, the failure rate function of each subsystem was driven using the failure density function (Equation 1). Then, the failure rate curve of each subsystem was plotted using the mentioned equation as illustrated in Figure 6. Results showed that failure rate for every subsystem was different. Average failure rate after 1800 working hours for 2 years (every sugarcane harvester have worked about 900 h annually) for subsystems namely hydraulic, mechanical and electrical were calculated 0.087, 0.052 and 0.012 respectively and the failure rate for whole system was 0.15 h^{-1}, respectively. Furthermore, MTBF after 1800 h, working hours were computed 11.46, 19.35 and 85.71, respectively and for whole machine was 6.64 h for the aforementioned subsystems. Among the three investigated components, hydraulic subsystem with maximum failure rate and minimum MTBF and electrical subsystem with minimum failure rate and maximum MTBF were recognized the most unreliable and reliable subsystems respectively. Table 3 shows the values of failure rates and MTBF after 1800 working hours for subsystems.

Table 3 Failure rate, MTBF and MTTR for subsystems of sugarcane chopper harvester

Subsystems	Failure number	Failure rate	MTBF (h)	MTTR (h)
Hydraulic	157	0.087	11.46	2.02
Mechanical	93	0.052	19.35	2.15
Electrical	21	0.012	85.71	1.75
Total	271	0.15	6.64	2.1

As can be seen in Figure 6, the failure rate of hydraulic system is <0.133f/h at the beginning and it decreases to 0.07 and operates in this level for 600 h, then starts to increase and continues at this increased rate to the end. Regarding the shape of FR curve, design characteristics, experimental judgments and the available field data, the burn-in time for hydraulic system is 300 h and the related failure rate in this time is 0.101f/h. In the mechanical system, 200 h was defined as burn-in time. The FR of this subsystem starts from 0.06 and decreases to 0.04 at the end of the burn-in time. After 600 h, the FR decreases with very low rate and approaching to be constant. Therefore, this subsystem, which has passed 800 h of its useful life, is in good operational condition. The FR of electrical system starts from zero and rapidly increases and reaches the peak FR at 0.02 and then, it decreases throughout the lifecycle. The curve shows that the FR has reduced to 0.0066 after about 900 h operations. According to the above results, the hydraulic system needs more onsite service and maintenance because of their increasing failure rates.



(a)Hydraulic system (b)Mechanic system (c)Electrical system

Figure 6 The failure rate plots of sugarcane chopper harvester machine

3.3 Availability analysis

Results of availability analysis showed, electrical failures occurs less than hydraulic and mechanical failures subsystems. Availability of electrical subsystem is 98% that it is more than other subsystems. However, hydraulic subsystem with 85% has minimum availability between sugarcane harvester subsystems. Total availability for sugarcane harvester was 76%. It means, in 76% of performance hours, machine will be ready to operation. The sugarcane harvester is a hydraulic machine. It means, requirement power provide from hydro-motors that they circulate by hydraulic power of hydraulic pumps. Then, it seems minimum availability for hydraulic subsystem is logical.

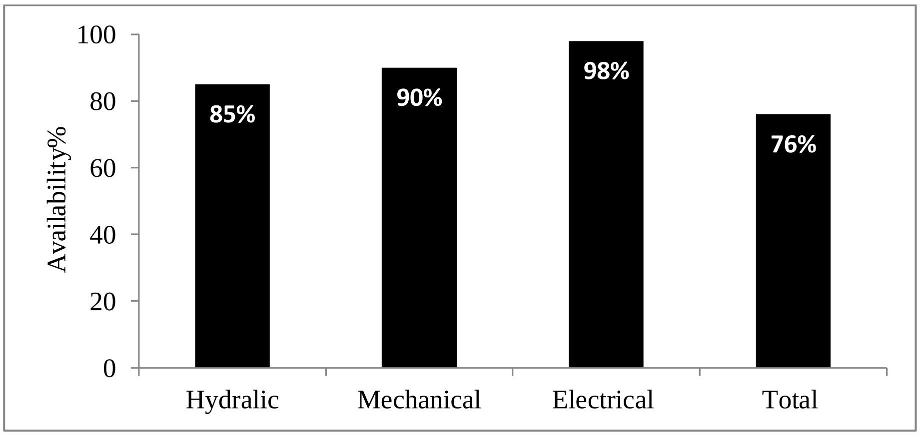


Figure7 Availability of sugarcane chopper harvester subsystems

4 Conclusions

In order to control and reduce failure and to plan and schedule the harvester operations in optimum time, we have to know how many failures occur in each term of machine performance and number of mean time between failures. Thus, to specify the failure rate and mean time between failures of sugarcane harvester the study was conducted in Hakim Farabi agro–industry of Iran. The failure rate of subsystems including hydraulic, mechanical and electrical were calculated 0.087, 0.052 and $0.012h^{-1}$, respectively and the failure rate for whole system was 0.15 h^{-1}. MTBF after 1800 working hours were obtained 11.46, 19.35 and 85.71h for the aforementioned subsystems and for whole machine was 6.64h. Among the three studied subsystems, hydraulic with maximum failure rate and minimum MTBF and electrical subsystem with minimum failure rate and maximum MTBF were recognized as the most unreliable and reliable subsystems respectively. Moreover, availability analysis showed availability for hydraulic, mechanical and electrical subsystems were 85%, 90% and 98%, respectively. However, total machine availability was 76%.

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