ISSN 2229-5518

Reliability Modelling of Side Discharge Loader for Availability Estimation and Maintenance Planning in Underground Coal Mines

Sankha Sarkhel[1*], U.K. Dey[2]

Abstract-- The production and productivity in underground coal mines of India over the years is decreasing at an alarming rate. For improvement in production and productivity, mechanization has become an important aspect for Indian coal industry especially in case of underground coal mines to sustain in global scenario. Side Discharge Loaders as loading system has made possible major breakthroughs in increasing production and productivity. Side Discharge Loaders (SDL) is now used as a dominant loading machine for intermediate face mechanization in underground coal mines. To meet the production and productivity issues, the SDL machine should be reliable and maintained effectively and efficiently to have maximum availability. Higher availability of machine shall enable optimum utilization thus increasing production and productivity of these capital intensive equipments. This paper seeks to study the reliability, availability and maintainability (RAM) of an SDL machine with failure and repair data by Markov modeling. The constraints and reasons for machine unavailability are highlighted. The reliability and maintainability of SDL and its subsystems are evaluated. Reliability and maintainability of an SDL system are disappointing. There is scope to take decisions on optimal maintenance planning and machine improvement from this analysis.

Keywords-- Side Discharge Loaders, performance assessment, reliability, availability, maintainability, failure rate, repair rate, mean time between failures, mean time to repair, Markov model.

1 INTRODUCTION

Coal India Limited, because of its improved performance on an overall basis has got the Maharatna Status, however the performance of its underground mines has largely been unsatisfactory with a few exceptions in one or two subsidiary companies. Majority of its underground mines are making losses. However, some of the underground mines of Eastern Coalfields Limited (ECL), Bharat Coking Coal Limited (BCCL) and Central Coalfields Limited (CCL) are not amenable to total mechanization due to geo-mining conditions that are not conducive to mechanization and a consequential suboptimal level of evacuation capacity as shown in Table 1.

The overall coal production is below the target from underground mines of CIL. Relatively better performance in the SECL mines are observed because of the already existing Side Discharge Loaders and Load Haul Dumpers technology in most of the mines.

Conditions are worst in BCCL and ECL mines where SDL are introduced in most of the underground coal mines but their performance is not satisfactory. Losses in underground mines is essentially due to lack of modernization, poor maintenance and spares management of production machinery, old and deepening mines with difficult geo-mining conditions and increasing cost of mining day by day.

- *1* Research Scholar & Faculty Member, Department of Mining Engg. BIT Sindri, Jharkhand, India. Mob- +91-9334015964, Email- sankhasarkhel@gmail.com*
- *2 Professor & Head, Department of Mining Engg. BIT Sindri, Jharkhand, India. Email- dr_ukdey@yahoo.com*

*(* Corresponding Author)*

Table 1 - Production performance of BCCL from 1974-75 to 2014-15

Year	U/G (MTe)	O/C (MTe)	Total
2014-15	2.03	32.48	34.51
2013-14	2.7	29.91	32.61
2012-13	3.15	28.06	31.21
2011-12	3.48	26.72	30.20
2010-11	3.70	25.31	29.00
2009-10	3.90	23.61	27.51
2008-09	4.13	21.38	25.51
2007-08	4.46	20.75	25.21
2006-07	4.90	19.30	24.21
2005-06	5.47	17.84	23.31
2004-05	6.38	15.94	22.32
2003-04	6.74	15.94	22.68
2002-03	7.29	16.86	24.15
2001-02	7.59	17.66	25.25
1994-95	11.49	17.26	28.75
1984-85	13.34	8.50	21.84
1974-75	15.64	2.10	17.74

While addressing production and productivity scenario for their substantial improvement, it is essential to keep in mind the better environmental with the present and eco-friendly status of this method, vis-a-vis, and Open Cast mining. This is further emphasized by the fact that the workable seams in most of the mines getting increasingly deeper and in a decade or so may go beyond the economic stripping limit notwithstanding the development in the reach and capacity of

ISSN 2229-5518

the open cast excavators. Environmental impact of opencast mining is a growing concern in view of expected level of green and clean mining. [1]

SDL (Side Dump Loaders) is now used as a loading machine for intermediate mechanization in underground coal mining. Reliability assessments of repairable machines have been explored in some papers. The basic methodology for reliability modelling to analyse the failure characteristics of a repairable machine is presented by Ascher et al.2 and Samanta et al. (2001(a,b) and 2002). Failures of a repairable machine have been modelled on the basis of a renewal process, a homogenous or a non-homogenous Poisson Process (NHPP), or a proportional hazard process. In the renewal process, the times between failures (TBF) are assumed to be independent and identically distributed (iid) and failure data are characterized for modelling by a suitable probability distribution function. NHPP or the power law process is a time-dependent model. In the homogenous Poisson Process, TBFs are assumed to be exponentially distributed or have a constant failure rate. In this paper, the reliability as well as maintainability analysis of mining machines, based on the Markov process, has been proposed.

In real life, failures of SDL subsystems are randomly stochastic. These subsystems can be brought back into serviceable condition after repair or replacement. It is interesting to note that the failure of sub-systems and their units can never be predicted precisely as they depend upon the operating conditions, mining environment, and repair policy used in the mine. Again, the performance/ effectiveness of an SDL machine depends on the reliability, availability and maintainability characteristics of subsystems, maintenance efficiency, operation process and the technical expertise of the miner etc. Availability is a function of reliability and maintainability. The return on investment on a piece of equipment can be maximized by optimizing its availability. Information on system behaviour and failure modes is extremely important for taking decisions on maintenance strategy or action. So measuring the effectiveness of an SDL system using reliability modelling and performance analysis by Markov modelling appears to be appropriate. A study, therefore, is to be conducted for analysis of reliability, availability and maintainability (RAM) of an SDL machine in underground mines where SDLs are deployed at faces for coal loading. This paper deals with RAM modelling and performance analysis of SDL machine failure and repair data analysis using a Markov model. Suitable conclusions have to be drawn on the basis of this analysis. [2]

For the reliability modelling and performance analysis of SDL machines a step-by-step study procedure has been developed. A description of an SDL machine is given at the beginning. In the next section a reliability block diagram (RBD) of the SDL machine has been developed. Markov's transition diagram has been presented, making some assumptions. From the transition diagram, state transition linear differential equations are derived for the Markov process and then the steady state performance of SDL machines will be discussed.

2 DESCRIPTION OF SDL MACHINE

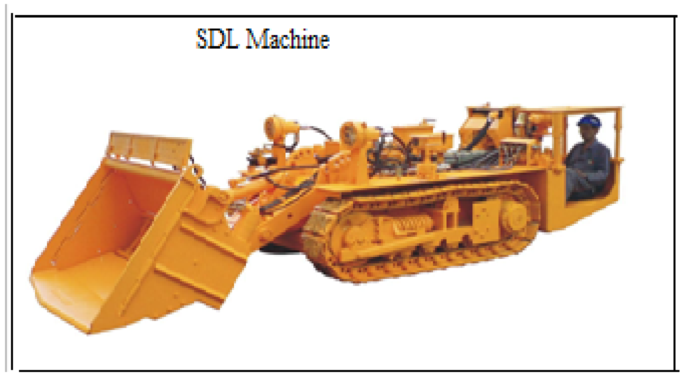

FIGURE 1 -SDL Machine

The machine is designed to work in underground coal faces to scoop and load run of mine coal in to transport equipment viz. coal tubs, belt conveyor and light duty chain conveyor. Side Dump Loaders (SDL) is now a dominant machine for intermediate face mechanization. It is typically trackless equipment mounted on crawler track assembly. The machine is able to work on load in the Inline gradient of 1 in 4 and Cross gradient of 1 in 8. It has a front-end bucket fitted with chain conveyor designed to carry and dump bulk material in either sides while lifting the side flap. Since an SDL is conceived for underground mining, it is compact and of low profile. It has a bucket capacity of 1 m^3. It is bi-directional in operation, with powered steering controlled by a driver sitting mostly along the direction of the vehicle's movement. It is driven by a s Squirrel Cage Induction motor having K.W. rating of Electric Motor 500 / 550 V, 55 HP (41 KW) fed with power from a gate end box suitably placed with a flexible cable of about 100 metres in length. The speed of the vehicle is controlled mechanically. The transmission is controlled by a hydrostatic drive. In hydrostatic transmission, the motor drives a variable displacement pump hydraulically connected to a hydro-motor driving the axle via a gearbox. The speed is controlled by changing the displacement volume of the axial pump. The power train consists of a closed loop hydraulic transmission, parking brakes, two-stage gear box, drive lines front axle with no-spin and rear axle without no-spin. Maximum crawler speed is up to 3.3 KMPH. Four multi-disc service brakes are mounted on the rear and front axles. A 275 litre tank capacity fed hydraulic pump caters for service requirements such as hoist, dump, steering, brakes, traction and reeling and unreeling of cable. An orbital is used for power steering. The cable drum accommodates 150 m of 4 x 25

ISSN 2229-5518

sq.mm type trailing cable. An automatic cable reeling device is fitted for smooth operation of the machine. Pumps are driven by a hydraulic motor. The effective operational range of the machine is 130 m radius. All hydraulic operations are piloted to facilitate operation of the machine from the driver's seat.

3 RELIABILITY PARAMETERS

A. Reliability

• "The Reliability of an item/system is the probability that the item/system performs a specified function under specified operational and environmental conditions at and throughout a specified time." Quantitatively, reliability is the probability of success. Usually expressed as Mean Time Between Failures (MTBF)

Mathematically, this may be expressed as,

$$R(t) = Pr\{T > t\} = \int_t^{\infty} f(x)\,dx ,$$

• "A collection of planned activities (established through formal and informal management systems), that are effectively working together to prevent loss of system function."

This second definition is a managed approach to maintain the reliability of system functions. Both definitions refer to the system and maintaining the functionality of the system.

B. Maintainability

• Maintainability: The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required function(s), when maintenance is performed under stated conditions and using prescribed procedures and resources. Expressed as Mean Time To Repair (MTTR).

C. Availability

• Availability: Is the probability that a system is available for use at a given time- a function of reliability and maintainability. It is operating time divided by load time, which is the available time per day minus the planned downtime.

• Failure: The termination of the ability of an item to perform its required function.

Inherent availability considers only corrective maintenance in an ideal support environment (with neither administrative nor logistic delays.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

When equipment is in a failed state it is no longer available for work, and its reliability decreases. As the length of time in a failed state (downtime) increases, the maintainability of the equipment decreases.

4 RELIABILITY BLOCK DIAGRAM (RBD)

It is necessary to construct a reliability block diagram (RBD) of the SDL system for reliability modelling and performance analysis. It is a graphical representation of the components of the system from a reliability viewpoint. The SDL machine is considered to be a system consisting of six major subsystems such as a power generating unit/drive unit, transmission, hydraulic, track chain, a bucket, electric and others, are connected in series. The reliability block diagram (RBD) of an SDL has been developed and is presented in Figure 2.

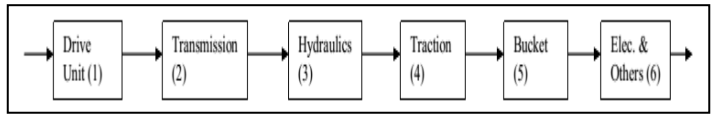

FIGURE 2 - RBD of SDL

5 ASSUMPTIONS AND NOTATION USED FOR MODELLING

For the purpose of modelling the following assumptions were made:

- Failure rates and repair rates for all the subsystems of the SDL are constant over time and statistically independent.
- Time between failure (TBF) and time to repair (TTR) data are exponentially distributed. So there are no simultaneous failures of subsystems and the probability of more than one failure or repair in a time interval is zero.
- The repaired units are as good as new (AGAN) one. Repair or replacement is carried out only in case of failure

Any subsystem of the SDL remains in either of two states only: the operating/up state and the non-operating/down state. The machine moves from the up state to down state as a result of a subsystem failure; similarly, the subsystem as well as the machine move at the same time from the down state to the up state as a result of repair. The probability of transition from one state to any other state does not depend on the state that was occupied earlier in the process. Sometimes the machine is in an underrated working capacity, but for simplicity it is taken as operating.

In the Markov model, the SDL machine as a system is represented with seven possible states as follows:

$PS_0(t)$, represents the probability that the SDL machine is in the 'up' state (S_0) at time t.

$PS_i(t)$, represents the probability that the subsystems are in the 'down'(S_i) state at time t. (i=1,2,…6).

λ_i is the failure rate of the subsystem (i =1,2,…..6).

μ_i is the repair rate of the subsystem.

Steady state availability of the SDL is found as

$P_0 = 1/\ (1 + \Sigma\lambda_i/\mu_i) = 1/(1+ D)$, where $D = \Sigma\lambda_i/\mu_i$

$P_1 = (\lambda_1\ /\ \mu_1)\ 1/\ (1+D)$

$P_2 = (\lambda_2\ /\ \mu_2)\ 1/\ (1+D)$

$P_3 = (\lambda_3\ /\ \mu_3)\ 1/\ (1+D)$

ISSN 2229-5518

$P_4 = (\lambda_4/\ \mu_4)\ 1/\ (1+D)$
$P_5 = (\lambda_5\ /\ \mu_5)\ 1/\ (1+D)$
$P_6 = (\lambda_6\ /\ \mu_6)\ 1/\ (1+D)$

Flowchart of reliability modeling of SDL by Markov Process is shown in Figure 3.

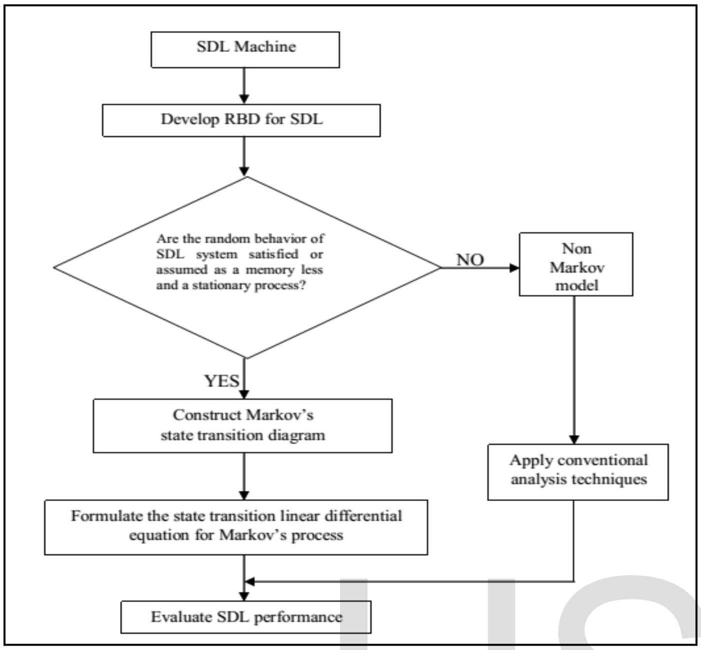

FIGURE 3 - Flowchart of reliability modelling of SDL by Markov Process

6 TRANSITION DIAGRAM OF SDL

The transition diagram for an SDL machine is presented in Figure 4. Based on the above RBD, assumption and failure rates and repair rate etc. are shown in Table 2. The operating state is denoted by the number '0' and the non-operating or fail state is denoted as 'i'(i= 1,2 ..6). At the beginning (i.e., at t= 0) , the machine is in the operational state and once the subsystems of the machine enter the non-operating state, it may return only to an operating state and vice versa, i.e. transition occurs only between the up state and down state.

Here subsystems reside in a discrete state and are continuous in time. So from the above discussion the problem can be modeled as the Markov Process. Here machine and subsystems are in a communicating state. The different equations related to the transition diagram are formed. The steady state availability of the machine, as well as different subsystems, are derived from these equations and the reliabilities of the machine, as well as its different subsystems, are estimated with different mission times.

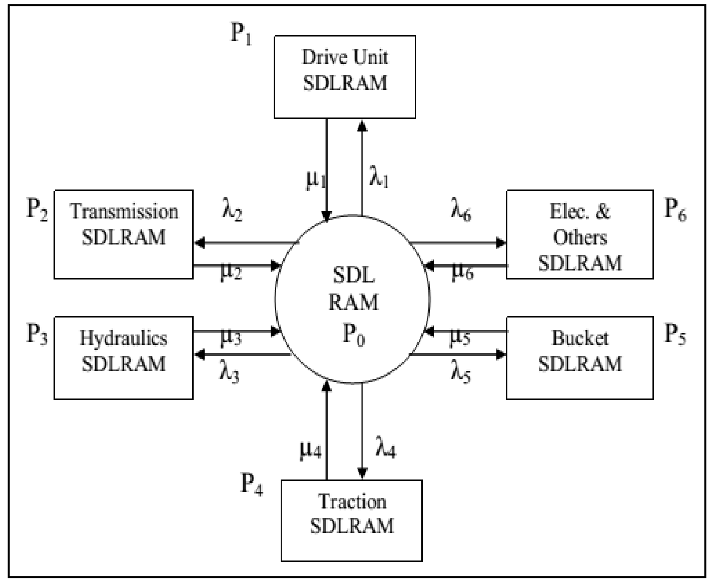

FIGURE 4- Transition diagram of SDL

7 RAM MODELLING OF THE SDL SYSTEM

From the transition diagram presented in Figure 4 and the Markov equations, the steady state availability of the SDL is found as:

$P_0=1/\ (1 + \Sigma\lambda_i/\mu_i) = 1/(1+ D)$, where $D = \Sigma\lambda_i/\mu_i$

The reliability of different subsystems and machine

$R_1(t) = e^{-\lambda 1t}$, $R_2(t) = e^{-\lambda 2t}$, $R_3(t) = e^{-\lambda 3t}$, $R_4(t) = e^{-\lambda 4t}$,
$R_5(t) = e^{-\lambda 5t}$, $R_6(t) = e^{-\lambda 6t}$

As subsystems are connected in series, so the reliability of the SDL system will be the product of the individual subsystem reliabilities.

$R_{SDL}(t) = \prod R_i = R_1R_2R_3R_4R_5R_6= e^{-\lambda 1t}\ e^{-\lambda 2t}\ e^{-\lambda 3t}\ e^{-\lambda 4t}\ e^{-\lambda 5t}\ e^{-\lambda 6t} = e^{-\Sigma\lambda it} = e^{-Ft}$ where $F = \Sigma\lambda_i$, i = 1,2,…6.

The maintainability of different subsystems and machine is as follows:

$M_1(t) = 1- e^{-\mu 1t}$, $M_2(t) = 1- e^{-\mu 2t}$, $M_3(t) = 1- e^{-\mu 3t}$,
$M_4(t) =1- e^{-\mu 4t}$, $M_5(t) = 1- e^{-\mu 5t}$, $M_6(t) = 1- e^{-\mu 6t}$

As a system, machine failure rate is $\Sigma\lambda i$ So MTTF = $1/\Sigma\lambda i$ = 1/F

It is known that for steady state availability (A) = MTTF / (MTTF + MTTR).

So MTTR = MTTF x D , where $D = \Sigma\ \lambda_i/\mu_i$

System repair rate (μ_s) = 1/MTTR = 1/MTTF x D

SDL machine maintainability $M_s(t) = 1- e^{-\mu st}$

Again, $R_{SDL}(t) = e^{-Ft}\ \therefore t = -\ln R_{SDL}(t)/F$

Thus, from different expected reliability of the SDL system the maintenance interval can be estimated.

8 FIELD INVESTIGATIONS

Collection of accurate and sufficient failure and repair data is necessary in machine reliability and performance analysis for achieving accurate results that are really helpful for mine management in decision making. Data collected from the field are assumed to be the most realistic. Field data are, however, tedious and time consuming to collect and subject to discrepancy. Again, data are required to be collected over a period of time for providing satisfactory representation of the true operational characterization of the machine. The authors have wide experience of mine environmental and closely involved with SDL operation in the past. Failure and repair data are recorded on the operation sheet and maintenance log book at each shift. The study was held at nearby underground mine owned by BCCL. The machine deployed in development heading for loading in tubs discharging the loads sideways mostly in level and rise galleries. Initial phase is by collecting the data regarding the operation schedule of SDL machine for a period of six months during the month of November-2014 to April-2015 were taken. The machine under investigation is in operation for past 17 months. Then data is sorted and classified based for each subsystem on number of failures, failure date, failure modes, type of failure, machine run hours, duration of maintenance, type of maintenance action , breakdown hours and repair hours. The failure and repair rate of SDL and its different subsystems are given in Table 2.

For general, the step-by-step process can be explained as follow:

• Understand the system and identified the subsystem when the failure occurred

• Collecting, sorting, and classification of data based on TBF and TTR from each subsystem.

• Data analysis and verification by using iid (independent and identically distributed) assumption from TBF and TTR data.

• Calculate the probability distribution of TBF and TTR from each subsystem.

• Estimate the reliability and availability for each subsystem based on the type of probability distribution.

•Identification of critical subsystem and determine the maintenance policies for improvement of reliability and availability of equipment.

The SDL remains a major constraint in achieving desired mine output. Reasons for low availability, poor working performance and alternatives at the mine to improve machine performance are given below. Problems faced in the colliery can be grouped into two categories thus environmental and technical.

A. Environmental

1. *Humidity*

High humidity causes moisture deposition, accumulating dust is the reason for machine getting heated and electrical failure due to short circuiting. Solution for the problem is by air flushing to washout the sticky dust.

2. *Water Seepage*

There is no problem when operating the SDL on the dry floor. But where seepage of water is there, the floor becomes mucky with the movement of the SDL. The crawler gets submerged in the muck. This resulted in an extra load on the machine. This problem has been partly solved by arresting the seepage water collecting in ditch formed at the rise side.

3. *Temperature*

It was observed that the hydrostatic unit of the machine would get overheated in continuous operation. It was found that when oil temperature rose beyond 65°C, the machine would start losing output power, causing difficulties in coal loading, hauling load on the up gradient. For the above problem, the machine had to keep idle and the oil is to be changed frequently. It was found that the hydrostatic pump performance improved considerably.

4. *Dust*

Coal dust at the face creates problems due to the frequent choking of the shuttle valves; pipes vents etc. Air flushing at regular interval to get rid of the dust was done.

5. *Visibility*

Operators face the problem of haziness caused due to dust and humidity. This is sorted out by cap lamps in clusters placed at strategic points.

B. Technical

1. *Cable reeling*

The cable reeling device fails frequently. These would break and snatch cable, causing cable damage. The cable is handled manually.

2. *Articulation*

The articulation chassis bolts broke frequently. This results in strain on the chassis and hairline cracks developing along the row of bolt holes. The holes also get larger causing loosening and breakage.

3. *Gear box*

The gear box mounting bolts in the chassis gets loosened frequently, causing damage to threads in the gearbox.

4. *Gate end box*

The failure in the gate end box is due to contactor switch dysfunction by overload causing tripping of the supply.

5. *Hydraulic hoses and seals*

Hydraulic hoses and seals failure occurs now and then requires replacement.

6. *Bucket*

Bucket lift cylinder pin fail due to wear in regular succession. Conveyor of bucket gets clogged when large sized lump is encountered.

7. *Crawler chain*

Crawler chain fasteners wears for specific run hours, need scheduled replacement.

Table 2 - Failure and repair rate of SDL subsystem

SDL subsystem	CTBF	Number of failures	Failure Rate (λ_i)	CTTR	Number of repairs	Repair Rate (μ_i)	λ_i/μ_i
Drive Unit	2803	20	0.00713	132	20	0.15151	0.047056
Transmission	2993	20	0.00682	160	20	0.12500	0.054560
Hydraulics	1380	20	0.01444	138	20	0.14492	0.099641
Traction	6812	20	0.00293	152	20	0.13157	0.022269
Bucket	1841	20	0.01086	109	20	0.18348	0.059189
Elec. & Others	1249	20	0.01601	105	20	0.19047	0.084055
			$\Sigma\lambda_i = 0.05819$			$\Sigma\mu_i = 0.92695$	D=0.366770

Substituting the values of λ_i and μ_i in equation, the steady state availability of SDL system is given by:

$P_0 = 1/(1 + \Sigma\lambda_i/\mu_i) = 1/(1+ D)$, where $D = \Sigma\lambda_i/\mu_i$

$P_0 = 0.7316$ where, D=0.366839

Steady state unavailability of different subsystem of SDL from equation is given below:

$PS_i(t) = (\Sigma\lambda_i/\mu_i) \times 1/(1+ D) = (D) \times 1/(1+ D)$

Steady state availability and unavailability of SDL system and its different subsystem along with percentage availability and unavailability is given in Table 3 below.

Table 3 - Steady state availability and unavailability of SDL and its subsystem

SDL and its subsystem	Probability of working state	Failed state	Probability of failed state	% Availability	% Unavailability
SDL	P_0=0.7316	SDL	0.2684	73.16	26.84
Drive Unit	S	P_1	0.0345		3.45
Transmission	D	P_2	0.0399		3.99
Hydraulics	L	P_3	0.0729		7.29
Traction	R	P_4	0.0163		1.63
Bucket	A	P_5	0.0433		4.33
Elec. & Others	M	P_6	0.0615		6.15

Failure rate of SDL = $\Sigma\lambda i$ (as units are connected in series) = 0.05819/h

Hence mean time to failures (MTTF) of SDL = $1/\Sigma\lambda_i$

= 1/F = 1/0.05819 = 17.1850 h.

SDL system reliability with time

$R_{SDL}(t) = e^{-\Sigma\lambda i\, t} = e^{-0.05819t}$, $t = -\ln R_{SDL}(t)/0.05819$

MTTR = MTTF x D = 17.1850 x 0.366839 hr = 6.304 h

SDL system repair rate (μ_s) = 1/ (17.1850 x 0.366839)

= 0.15862/h

∴ SDL system maintainability with time, $M_{SDL}(t) = 1- e^{-0.15862t}$

Table 4 - Reliability and Maintainability of SDL and its subsystem

SDL and its subsystem	Reliability	Maintainability
SDL	$R_{SDL}(t) = e^{-0.05819t}$	$M_{SDL}(t) = 1- e^{-0.15862t}$
Drive Unit	$R_1(t) = e^{-0.00713t}$	$M_1(t) = 1- e^{-0.15151t}$
Transmission	$R_2(t) = e^{-0.00682t}$	$M_2(t) = 1- e^{-0.12500t}$
Hydraulics	$R_3(t) = e^{-0.01444t}$	$M_3(t) = 1- e^{-0.14492t}$
Traction	$R_4(t) = e^{-0.00293t}$	$M_4(t) = 1- e^{-0.13157t}$
Bucket	$R_5(t) = e^{-0.01086t}$	$M_5(t) = 1- e^{-0.18348t}$
Elec. & Others	$R_6(t) = e^{-0.01601t}$	$M_6(t) = 1- e^{-0.19047t}$

Table 5 - SDL and its subsystem reliability at different times

Time (Hr)	Drive Unit	Transmission	Hydraulics	Traction	Bucket	Elec. & Others	SDL
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	0.8671	0.8724	0.7497	0.9436	0.8057	0.7261	0.3122
40	0.7518	0.7866	0.5621	0.8904	0.6492	0.5272	0.0975
60	0.6532	0.6976	0.4214	0.8402	0.5230	0.3828	0.0304
80	0.5652	0.6187	0.3160	0.7929	0.4214	0.2780	0.0095
100	0.4901	0.5488	0.2369	0.7482	0.3395	0.2018	0.0029
120	0.4250	0.4867	0.1776	0.7060	0.2736	0.1466	0.0009
140	0.3685	0.4317	0.1331	0.6663	0.2204	0.1064	0.0002
160	0.3195	0.3828	0.1308	0.6287	0.1776	0.0773	0.0000
180	0.2770	0.3395	0.0748	0.5933	0.1431	0.0561	0.0000
200	0.2402	0.3011	0.0561	0.5598	0.1153	0.0407	0.0000
220	0.2101	0.2671	0.0420	0.5283	0.0929	0.0295	0.0000
240	0.1863	0.2369	0.0315	0.4985	0.0748	0.0214	0.0000
260	0.1620	0.2101	0.0236	0.4704	0.0603	0.0156	0.0000
280	0.1408	0.1863	0.0177	0.4439	0.0486	0.0113	0.0000
300	0.1224	0.1652	0.0132	0.4189	0.0391	0.0082	0.0000
320	0.1064	0.1466	0.0099	0.3953	0.0315	0.0059	0.0000
340	0.0925	0.1300	0.0074	0.3730	0.0254	0.0043	0.0000
360	0.0804	0.1153	0.0056	0.3520	0.0204	0.0031	0.0000
380	0.0699	0.1022	0.0042	0.3322	0.0165	0.0022	0.0000
400	0.0577	0.0907	0.0031	0.3134	0.0132	0.0016	0.0000

Table 6 - SDL and its subsystem maintainability at different time

Time (Hr)	Drive Unit	Transmission	Hydraulics	Traction	Bucket	Elec. & Others	SDL
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.7410	0.7134	0.7652	0.7317	0.8403	0.8511	0.7952
20	0.9329	0.9179	0.9448	0.9280	0.9745	0.9778	0.9580
30	0.9826	0.9764	0.9870	0.9806	0.9959	0.9967	0.9914
40	0.9955	0.9932	0.9969	0.9949	0.9993	0.9995	0.9982
50	0.9988	0.9980	0.9992	0.9986	0.9998	0.9999	0.9996
60	0.9996	0.9994	0.9998	0.9996	0.9999	0.9999	0.9999
70	0.9999	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999
80	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	0.9999
90	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	0.9999
100	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	0.9999
110	1.0000	0.9999	1.0000	0.9999	1.0000	1.0000	0.9999
120	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
130	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
140	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
150	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
160	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
170	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
180	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
190	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
200	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

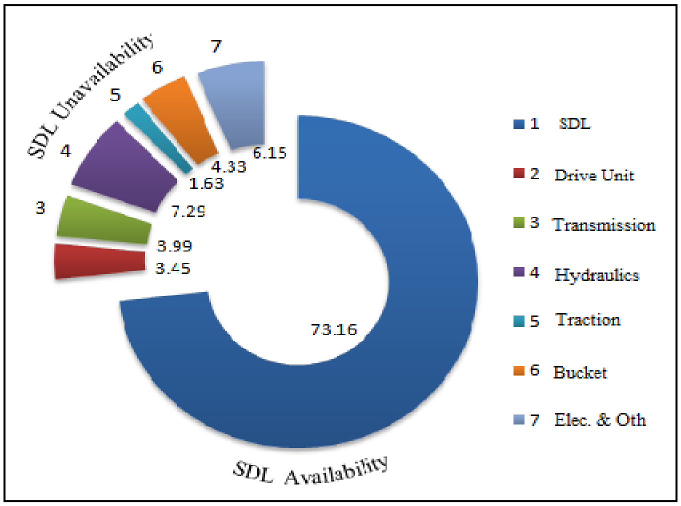

FIGURE 5 - SDL performance analysis

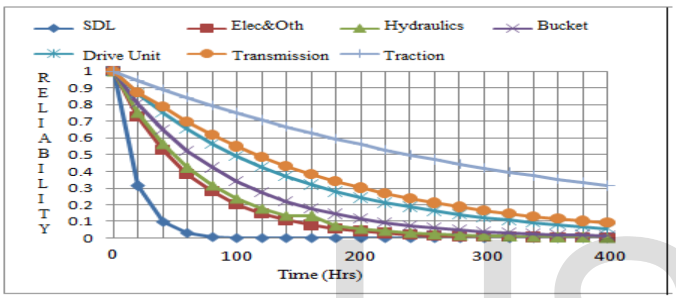

FIGURE 6 - SDL system reliability with time

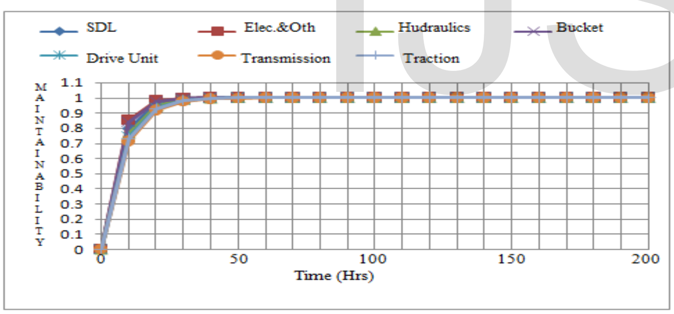

FIGURE 7 - SDL system maintainability with time

Table 7 - SDL maintenance interval for expected reliability

Maintenance interval (Hrs)	72	51	36	26	20	15	10	6.2	3.1	0
Expected reliability (%)	10	20	30	40	50	60	70	80	90	100

9 RESULTS AND DISCUSSION

It is observed that significant causes for machine unavailability are the hydraulics, bucket and elec. & others subsystems as shown in the Figure 5. The reliability and maintainability of the SDL and its subsystems with different mission times are presented in Tables – 5 and Tables – 6, and graphically shown in Figure - 5 and Figure - 6. From these, it is found that the reliabilities of the different subsystems are different as well as decreasing with time. It is also seen that [Rs(20) = 0.31], which means that machines will not fail for 20 hours of operation with only a 0.31 probability. It can also seen that there is a 95%, chance that any failure in the machine will be repaired within 20 h of repaired time [Ms (20) = 0.95]. There is a 100% chance that any failure in the SDL machines will be repaired within 140 h. With different expected reliabilities of the SDL system, the maintenance interval is given in Table - 7. It is also found that the reliabilities of the drive unit, transmission, traction, bucket, elec. & others, and hydraulic subsystems and SDL system are in decreasing order, respectively. The reliabilities of hydraulics, elec. & others and bucket as well as the SDL system are particularly unimpressive. The SDL system reliability drops sharply. Again, special attention is required to improve maintainability of the drive unit, traction and transmission, as well as the SDL system. Hence it is apparent that proper resource allocation in terms of skilled and trained manpower, spare parts, a maintenance strategy suitable for the environmental as well as technical problems, as stated previously, and specific maintenance can only reduce the frequency of machine failure or repair time and consequently improve the machine availability (i.e. reliability and maintainability). For a different expected reliability of the machine, the maintenance intervals are depicted in Table - 7 and graphically presented in Figure - 6 & 7. For example, the SDL must be maintained every 10 hr to have 70% machine reliability as shown in Table 7.

10 SUGGESTIONS

Ensuring timely and regular maintenance of the SDL machine will decrease the downtime. Routine inspection of the following parts should be carried out regularly as a part of maintenance planning.

- Daily maintenance

Checking the hose pipes for leakages
Bucket chain for wear and tear
Checking all the cylinders like lifting cylinder, roll back cylinder, etc
Cleaning of the machine by water sprinkling in order to facilitate identifying any damage

- Weekly maintenance

Checking of oil levels
Gear box checking
Control block checking
Checking of all bolts

- Half yearly maintenance

Control unit servicing
Drive unit servicing
Triple gear hydraulic pump replacement
Complete overhauling of the machine after a maximum of two years.

In addition, the electricity supply to the SDL gate end box (GEB) should be regularly inspected in order to prevent any chances of tripping and stoppage of production. Moreover, the trailing cable should be properly handled to ensure efficient operation and to prevent breakdown of the SDLs.

11 CONCLUSIONS

Different parameters of machine performance, such as reliability, availability, maintainability and factors responsible for unavailability are evaluated. It is found that the steady state availability of the SDL is 73.19%. A few significant causes of machine unavailability have been detected and they demand special attention. The main reasons for machine unavailability are hydraulics, elec.& others, bucket subsystems with 7.29%, 6.15% and 4.33% of working hours respectively. It is also seen that the reliability of the traction and transmission with time is not satisfactory. The overall reliability of the SDL system drops significantly with time. For improvement, the reliability of those subsystems/machines requires strengthening the maintenance efforts, which can result in decreasing their failure rate or increasing their time to failure (TTF).

Maintainability of the traction and transmission are low. Breakdown time may also be reduced by proper planning and spare parts management for increased availability of the machine. There is wide gap between failure time and repair time which suggests there is lack of team effort which causes increased downtime of machine affecting availability. The constraints and reasons for low reliability and maintainability suggested that possible modification and design alternatives of the machine especially its hydraulics system and bucket should be considered. From the above discussions and analysis, it is evident from the fact that there is scope for better maintenance planning and thus improving the RAM of the machine from this type of modeling and quantitative analysis by the Markov processes. The case study provides data for predicting the control needs in maintenance or repair processes and scheduled maintenance planning to ensure a desirable level of the SDL system's reliability, availability and maintainability optimizing the utilization of the machine from production and productivity point of view. Many of the measures suggested in this paper can be implemented with minimal effort and could have a profound effect on improving productivity at a minimal cost.

ACKNOWLEDGEMENTS

The authors are thankful to the mine management for providing necessary help and suggestions during field study. The views expressed in this paper are solely of the author and not necessarily of any organization.

REFERENCES

[1] Sankha Sarkhel and U.K. Dey. (2015), A critical study on availability and capacity utilization of side discharge loaders for performance assessment. IJRET, Volume: 04 Issue: 07 |eISSN:2319-1163| pISSN: 2321-7308, pp.251-258

[2] B. Samanta, B. Sarkar, and S.K. Mukherjee (2004) Reliability modeling and performance analyses of an LHD system in mining: The Journal of The South African Institute of Mining and Metallurgy, January/February 2004

[3] M.E. Michael Arputharaj (2015): Studies on availability and utilization of mining equipment-an overview, IJARET, Volume 6, Issue-3, pp. 14-21.

[4] New Technology and Challenges for Underground Coal Mining.(2013) [online]www.ibkmedia.com/userfiles/.../event_8-8-3-50058b712259a.doc

[5] Devi Prasad Mishra, Mamtesh Sugla, Prasun Singha (2013): Productivity improvement in underground coal mines – a case study, J. Sust. Min. Vol. 12, No. 3, pp. 48–53

[6] ASCHER, H. and FEINGOLD, H. (1984), Repairable system reliability. Dekker, New York

[7] KUMAR, U. and HUANG, Y. (1993). The application of Markov chain for studying the operational reliability of the production system at KIRUNA mine. In Safety and Reliability Assessment—an integral approach. Kafka, P. and Wolf, J.(eds). Elsevier Science Publications pp. 629–636

[8] PARASZCZAK, J. and PERREAULT, F. (1994), Reliability of diesel powered load-haul dump machines in an underground Quebec mine. CIM Bulletin, vol. 87, no. 978, pp. 123–127

[9] Dhillon, B.S. (2000) Engineering Maintainability. Prentice-Hall India, New Delhi

[10] Srinath, L.S. Reliability Engineering. (1991) Affiliated East-West Press Pvt. Ltd.

[11] Kumar U., (1988) "Reliability technique: A powerful tool for mine operators", Mineral Resource Engineering, vol.1, 13-28,

[12] Nuziale T. and Vagenas N., (2000) "Reliability assessment of mining equipment using genetic algorithms", Mine Planning and Equipment Selection, Panagiotou & Michalakopoulos, Balkema, Rotterdam, 841 – 846,

[13] J. Maiti, and Dasgupta, S. (2001) Reliability modelling of repairable systems—an application of NHPP model to LHD machine. Proceedings, on Underground Mine Mechanization, ISM, Dhanbad, India, pp. 212–220.