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Assessing the Maintenance Strategies and Techniques Used in South African Power Plants: A Review

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Abstract

As part of the energy sector, power plants are vital to fulfilling any state's social and economic needs. To fulfill these needs, power plants should adopt effective maintenance practices. This ensures the reliability and availability of power plant assets, thereby enhancing productivity and safety. This paper aims to identify, analyze, and present maintenance strategies and approaches adopted in South African power plants. South Africa has relationships with various countries across the globe; hence they are paying attention to its energy and other sectors. South African power plants have been struggling for over a decade to have a stable power supply system. One of the critical issues is maintenance. Efforts have been made to enhance the maintenance of power plants. The study adopted a narrative literature review of various scholarly writings to identify and assess the extent to which maintenance strategies are used in power plants. Several maintenance strategies have been adopted in South African power plants, such as preventive maintenance, predictive maintenance, corrective maintenance, computerized maintenance management system, total production maintenance, and human factors in maintenance. This study will be helpful to researchers and maintenance practitioners cussing in the maintenance of power plants, especially in the South African context and developing countries.

Keywords
Human factors, maintenance, maintenance strategy, power plant, predictive maintenance, preventive maintenance

1. Introduction
Power plants are the lifeblood of social and economic development for developed and developing states. Their reliability and availability have a significant contribution to the social and business success of any country. According to Olesen and Shaker (2020) thermal power plants are critical assets in the present energy technical systems (equipment and infrastructure) with a mandate to provide services, energy and heat to their respective customers while maintaining a stable grid. As the demands to move to renewable energy intensify, operators find themselves under serve pressure (Olesen and Shaker2020). This pressure can be due to sophisticated maintenance required for new power plants and challenging maintenance for older power plants. The maintenance personnel need to ensure that state of the art maintenance practices are adopted to ensure the availability and reliability of that power plants infrastructure and equipment. Developed countries have achieved considerable success in reducing failures of power plant equipment such as boilers through the implementation of predictive maintenance strategies (Gabonewe at al. 2021). However, power plants in South Africa, which is this study's main focus, are finding it very difficult to adequately predict failures because they rely more on traditional maintenance strategies. Eskom, a state owned entity, generates a greater proportion (over 90%) of South African Electricity.

Majority of the South African power plants are coal-fired including the recently built huge Kusile (3200 MW) and Medupi (3970 MW) power plants. Asset management process of the South African power plants, especially Eskom should be able to provide the utilities adequate maintenance and management such that they are able to meet the consumption demands (Mutloane 2009). Regular maintenance can assist power plants to minimize the risks of unplanned shutdowns or failures. However, the challenge is to find an adequate maintenance strategy for huge and modern power plants infrastructures especially since they are faced by increase in burdening electricity demands (Schlunz and Van Vuuren 2012). In their study, Ndjenja and Visser (2015) discovered that many of the South African power plants had adopted a maintenance strategy that integrates a number of techniques such as time-based, run-to-failure and to-failure and condition based maintenance. The development and implementation of the a strategy is aimed at setting and achieving clear power plant maintenance objectives as revealed by authors such as Ndjenja and Visser (2015) which focused on the establishment of a maintenance strategy for power generation plants, especially in the South African context. Figure 1 below presents the power plants maintenance strategy objectives.

Figure 1. Maintenance strategy benefits

In the coming years, Eskom power plants are determined to enhance power generation performance, to achieve an estimated availability of 80% (Eskom, 2018). Eskom as adopted the following technical key performance indicators Eskom (2018):

- Lost-time injury rate (LTIR) (including occupational diseases)
- Planned capability loss factor (PCLF)
- Energy availability factor (EAF)
- System average interruption duration index (SAIDI)
- System average interruption frequency index (SAIFI)
- System minutes <1
- Distribution total energy losses

It is good to note that for South African power plants to realize these benefits measured through technical performance indicators they need to develop and adopt of a proper maintenance strategy. Part of the maintenance strategies is to prevent accidental failures. The study by Deac et al (2010) presented several measures that are taken to prevent accidental failures as listed in Table 1 below.

Table1. Measures of preventing the accidental failures (Adapted from Deac et al., 2010)

Measure	Sub-measure	Technique/s
Compliance with the fundamental maintenance conditions	---	○ Exploit techniques
Compliance with the conditions of usage	---	○ Maintenance techniques ○ Exploit techniques
Restoration after failure	Unearthing and prevention of failures	○ Maintenance techniques
	Standardization of repair methods	○ Maintenance techniques
Rectification of design failures	---	○ Maintenance techniques
Prevention of human errors	Prevention of maintenance errors	○ Maintenance techniques
	Prevention of exploit errors	○ Exploit techniques

Objectives
The aim of this paper was to identify, analyse and discuss the maintenance strategies and techniques used in South African power plants. The study established the following objectives:

- To identify and analyse maintenance strategies and techniques that are used in South African power plants.
- To discuss the extent to which maintenance strategies are used to enhance reliability and availability of power plants equipment and systems.

This study made contribution to maintenance research by an agenda for debate and further discussions socially with regard to maintenance of power plants in developing countries. This study also contributed to the practice of maintenance by discussing maintenance strategies and the extent of their utilization. This will help practitioners in prioritizing their maintenance efforts.

2. Literature Review Research Method

This study followed a narrative literature review research methodology to identify, analyze, summarize and discuss maintenance strategies used in adopted in South African power plants. It reviewed a number of scholarly writings and since it was a traditional literature review, it focused on journal articles, conference papers, reports, dissertations and books that were addressing maintenance of power plants in South Africa, especially if they focused on maintenance strategies or some aspects of strategies. These papers were accessed through research hubs such as Goggle Scholar, Indiserscience, Elsevier and others that could be accessed through free or open access publication and those that were accessible through the University of Johannesburg subscriptions. It was aimed at providing an overview on maintenance strategies adopted in South African power plants with an intention to create research agenda. Furthermore, provide clear summaries with regard to what has been adopted, the extent to which it has been adopted and where provided examine challenges associated with the adoption of these strategies.

3. Maintenance Strategies and Techniques Used in South African Power Plants

For the reliability electricity of energy supply and even during the times of energy transition requires power plant systems, equipment and technologies to be properly maintained through the adoption of effective and efficient maintenance technologies. This section presents the literature review of maintenance strategies and techniques that are adopted in South African power plants.

3.1 Breakdown Maintenance

The majority of South African power plants, predominantly older power plants were using “run to failure” or breakdown maintenance more than other maintenance tactics (Ndjenja and Visser, 2015). This means adopting a reactive approach to maintenance by doing maintenance after the asset or component of the asset has failed. In another study by Bembe (2013), it was revealed that the South African energy industry predominantly follows predefined time interval maintenance and reactive run-to-failure maintenance. These are traditional maintenance philosophies. So, engineers “simply react to the generator failure as and when it happens” (Bembe, 2013). It was indicated that many electricity utilities or power plants follow this reactive approach or run-to-failure maintenance when it comes to the maintenance of turbo-generators. Furthermore, the surveys of the study demonstrated that 40-60% of outages for generators operated in a cyclic manner were as a result of corrective maintenance. Gabonewe at al., (2021) evaluated the effectiveness of predictive maintenance approach in boiler systems. Their study showed that due to pressure in a South African power plant to meet the energy supply demand they made a decision to go for a run-to-failure maintenance approach thereby terminating planned maintenance schedules. This approach has made the boiler to operate for prolong hours at increased temperatures that imposed great strain leading to boiler tubes and other component failures. These power plants need a paradigm shift to achieve better maintenance results. Applying corrective or run to failure approach on each item of a physical asset may lead to huge maintenance costs thereby affecting future maintenance activities. The only advantage that run-to-failure has is that it allows the full utilization of the equipment’s design life in which it may be cheaper option for certain items (Ndjenja and Visser, 2015).

3.2 Deferred Maintenance

It has been a norm in South African power plants to postpone critical maintenance to avoid load-shedding (Petersen, 2016). The South African power plants resorted to deferred maintenance to meet the electricity demands due to the current electricity crisis (Govender, 2016).This practice has led to a number of units failing unexpectedly leading to the very severe load shedding than what they have been avoiding (Govender, 2016; Petersen, 2016). Maintenance teams need to understand that as much as avoiding maintenance has immediate benefits but it has long term consequences as proven in the South African power plants over the years. Furthermore, the usual maintenance approach in coal fired power plants that dominate the South African energy is corrective maintenance (Govender, 2016).

3.3 Preventive Maintenance

Preventive maintenance dominates the maintenance efforts of the South African power plants (Mamabolo, 2012). In the study it was stated that Eskom had adopted the Workweek Management programme to serve as an instrument for supporting preventive maintenance specifically time-based maintenance approach thereby enhancing maintenance practices. Furthermore it was reported that Matimba which was regarded as one of the high-performing power stations, had transitioned from the culture of only reviewing preventive maintenance reports on yearly basis to reviewing them as and when necessary.

Bembe (2013) indicated that among the traditional maintenance philosophies that are used in South African power plants is fixed time interval maintenance approach. For an example, with this approach the maintenance personnel conveniently do full inspections on the turbo-generator under relaxed production cycles. Furthermore, though they are using predictive maintenance as well, but it was revealed that the nature and frequency of condition monitoring used in rotating equipment that are operating at cyclic modes was not stable but variable.
Adequate monitoring of and adherence to planned maintenance schedules led to a slight enhancement in management of tube failures (Gabonewe at al., 2021). Thereby, leading to the achievement of the power plant objectives to decrease related incidents. Even though there has been some improvements, but compared to international best practices, the incidents are still high.

Prescheduled or planned outages were used in one of the South African plants as part of the maintenance procedure for establishing the appropriate time a certain unit can be taken out of service for a particular interval (Hedges, 2009). This forms part of the periodical or preventive maintenance approach.
Mwale and Davidson (2014) stated that Eskom established an outage management plan, which is part of the traditional preventive maintenance approach. The focus was on the following aspects:

- Annual planning and scheduling of outages
- Approving outage plans
- Performing scheduled outages
- Closing out outages

3.4 Predictive Maintenance

The maintenance of South African power plants has evolved over the years. For an example, Eskom maintenance incorporates a viable approach to maintenance, which is predictive maintenance strategy (Du Toit, 2014). Additionally, the adoption of proper predictive maintenance plans leads to approximately 25-30% reduction in maintenance costs and 70-75% decrease in equipment breakdowns (Pett eat al., 2003 cited in Du Toit, 2014). In the study by Ndjenja and Visser (2015) majority of the maintenance personnel stated that their power plants were using predictive maintenance specifically condition-based maintenance. However, a considerable number of maintenance personnel indicated that they were not using condition-based maintenance approach, thereby exposing the power plants to greater risks.

One of the power plants that was analyzed by Gabonewe at al. (2021) realized that, it was important to adopt predictive maintenance philosophy to address the issue of boiler tube leaks, thereby decreasing unplanned plant down times. They manually measured and recorded wall thicknesses during plant shutdowns and then loaded data into a computerized and simulation system. This was done to estimate and give warnings when there is a probability of boiler tube failures that might happen prior the planned outages, thereby avoiding unplanned shutdowns. After there was a slight improvement, the tube failures were still a concern, which is a sign that predictive maintenance system could still be enhanced for adequate prediction of failures. Without the adequate utilization of predictive and preventive maintenance, Eskom power plants are likely to suffer from hidden costs associated with maintenance labour (Mamabolo, 2012).

3.5 Computerized Maintenance Management System (CMMS)

The study by Gabonewe at al., (2021) examined the effectiveness of the predictive maintenance system for a boiler. It then revealed that, one of the South African power plants incorporated Computerized Maintenance Management System (CMMS) in the maintenance mix. Specifically, they used the Systems, Applications and Products (SAP) software for planning and scheduling their maintenance activities and managing inventory for power plant equipment with an exception of boiler systems. Furthermore, this power plant used Microsoft Excel for planning outages for boiler systems, instead of the CMMS, SAP, thus delaying boiler maintenance activities (Gabonewe at al., 2021). The SAP could have helped the power plant to process accurate information regarding the availability of materials and inventory necessary for boiler system repairs. Ndenja and Visser (2015) discovered that almost all power plants within the South African context that the SAP in maintenance. In the study by Hedges (2009) which focused on the development on an optimal maintenance scheduling model revealed that there is a computer program called Phoenix that was adopted in Eskom power plant specifically in the Transmission Division. This program was used to plan and schedule their maintenance. However, this program was only useful for data recording and keeping with regard to what was done and what still needed to be done. The application of a computerized decision support model helped a South African national power system to address and solve real-life problems associated with generator maintenance scheduling (GMS) (Schlunz and Van Vuuren 2012). This computerized model was found to be highly effective in determining adequate maintenance schedules thereby achieving its objective of solving generator maintenance problems. Tsekoa (2017) examined the use of CMMS in Eskom Camden Power Station within the study that was aimed at analyzing the barriers to implementation of equipment reliability enhancement strategy. In this study, many maintenance personnel agreed that their power plant was using CMMS, they had experienced in using it, but a few had been trained to use the program. This program was used in power plants for fulfil the objectives of preventive maintenance as well as to manage work orders and organization's maintenance resources. Furthermore, it supported the maintenance decision making process by providing sufficient information.

3.6 Risk Based Maintenance (RBM)

Power plants use a number of pressure equipment such as boilers, heat exchangers, pressure vessels and piping) in their processes. These equipment are highly regulated under pressure equipment standards and legislations. Now, Risked Based Inspection (RBI) has been introduced in recent years as a tool for improving maintenance plans thereby enhancing inspections, reduce risks and realize cost benefits. Singh and Pretorius (2017) revealed in their study that Eskom has implemented Risk Based Maintenance (RBM) approach which is based on the RBI concept. This was to ensure that Eskom plan their inspections in line with their energy demands, rather than having to do mandatory inspections during the times where there is a high demand for energy. Since this approach focusses on risks, evaluation and classification it helps in enhancing safety and compliance to legislative requirements thereby reducing maintenance and inspection costs. Furthermore, the RBM is used for the prioritization of resources (e.g. human, information, and technology) for adequate maintenance planning and scheduling (Singh and Pretorius, 2017). Data to be used with the RBM should be carefully collected to avoid errors, deviations and inaccuracies thereby leading to wrong risk assessment results. Hlophe and Visser (2018) conducted a study on risk management during power plant outage projects to address risks associated with costing and scheduling of complex projects. This study revealed that there is a deeper understanding of the project risk management process and practice within Eskom power plants within outage management. However, there was an unacceptable level of conformity, as a result it was not used consistently throughout the outage lifecycles.

Thereby leading to large cost and schedule overruns that could have been prevented by adequate use of the risk management process. There was hope for the improvement of the system since the maintenance personnel generally believed and understood the importance of risk management in outage projects. Furthermore, they identified management commitment, training and supportive culture as key to the success of the outage project's rick management process. Brand et al. (2016) Worked on a study that was aimed at determining the appropriate times for interventions in Eskom power plants because the current measures were not adequate. Their work was based on the premise of risked based inspection (RBI) where they focused on the maintenance history of the plant and mathematical modelling that resulted in determining appropriate times for conducting preventive maintenance. This was aimed at preventing the risk of utilizing more spare parts during corrective or reactive maintenance. The model summated various data related with routine test outcomes to predict failure. The model that was developed by Hedges (2009) was used for the estimating the remaining useful life of equipment or components with an aim of determining an adequate plan for performing maintenance or inspections at an appropriate time. This was done through the development of a mathematical model to be used with the historic operational data of equipment or comments to determine an optimal maintenance schedule.

3.7 Total Productive Maintenance

Jama (2022) studied the reliability analysis of a South African power plant and the potential role of Total Productive Maintenance in Duvha power station. The study revealed that, TPM had been partially implemented, as a result there were a number of challenges faced by power plant. Furthermore, employee involvement which is a critical element of TPM was found to be key in enhancement of power plant maintenance. Eskom engaged in a number of activities such as design constraints, rollout competences, and systems-based solutions with an aim of achieving sustainable total productive maintenance. However, the implementation of TPM would not be a success without adequate work management (Mutloane, 2009; Jama. 2022). Eskom requires to put more effort to ensure proper adoption of TPM and full realization of benefits. Mutloane (2009) Conducted a study that focused on employee engagement during the process of implementing work management which as key aspect of TPM. This method is adopted to eliminate wastage within the process, consequently enhancing productivity. It was intended to evaluate as to whether Matimba power station could be able to optimally utilize its resources while operation department conduct routine work, thereby affording the maintenance department time to focus on more complex and special maintenance activities. The study revealed that there was initial involvement of employees during the implementation of work management, but this was not maintained throughout the process. However, TPM in this power seemed to be operating at an acceptable level.

3.8 Reliability Centered Maintenance

There was less emphasis made to reliability centered maintenance in South African power plants. Sibanda (2016) studied the reliability centered maintenance (RCM) concepts with an intention to enhance boiler-coal processing plant in Eskom the major (90%) owner of the South African power plants. The study discovered that the application of RCM enhanced the availability of the equipment before they are taken out for preventive maintenance. Furthermore, its application did not impose additional cost to the organization. It is indicated that, the inspection data is a big issue because sometimes it is not up to date.

3.9 Human Factors in Maintenance

Human factors together with insufficient analysis of power plants history were found to be the main reasons for the inadequate scope of work and changes in outage intervals in South African power plants (Goliada, 2021). "The next step in the evolution of maintenance management is a maintenance performance measurement that includes human factors" (Peach et al., 2016). The study by Peach et al., (2016) assessed the inclusion of human factors in maintenance performance measurement framework in South African electricity transmission industry, particularly Eskom power plants. They discovered that majority of maintenance personnel received on-the-job training, other had certificates in preventive maintenance and most of them believe that they adequate training to execute their maintenance duties. Furthermore, the maintenance personnel in these power plants, believe that skill level, motivation, supervision, workload and feedback are key maintenance human factors. South African power plants provide opportunities for growth and development, development on the job, challenge teams to grow, provide good pay and benefits, environment that makes them feel valued and also social engagement (Peach et al., 2016).

Badenhorst and Van Tonder (2004) conducted a study to evaluate factors that lead to human errors in South African government-own power plants. They discovered human errors related with knowledge, skills and behavior such as competence-based deficiencies, communication-based deficiencies, socio-environmental deficiencies, mental and physical, ergonomics, procedural and many others deficiencies associated with human factors. Their study also revealed that with proper human factors approach, human error can be avoided or decreased within power utilities.
In many instances, the financial issues was not that the controls or defenses put in placed had failed but management interfered or overridden those controls (Eskom, 2018). These issues were not associated with maintenance, but the culture that led to them has affected maintenance. The South African power plants relied more on existing controls such as monitoring the progress of departmental meetings as well as enhancing supervision to address and prevent human induced failures or avoidable human errors (Goliada, 2021).

4 Key Findings and Classifications

The key findings were arranged in terms of the types of maintenance conducted in South African power plants. Table 2 below presents the types of maintenance practiced in South Africa.

Table 2. Types of Maintenance in South African Power Plants

No.	Author/s	Aim	Breakdown Maintenance	Deferred Maintenance	Preventive Maintenance	Predictive Maintenance	Computerized Maintenance Management System	Risk Based Maintenance	Total Productive Maintenance	Reliability Centered Maintenance	Human Factors in Maintenance
1.	Jama (2022)	Focused on the engineering modification processes and total productive maintenance.	.	.	.	.	.	.	✓	.	.
2.	Gabonewe at al. (2021)	Evaluated the effectiveness of predictive maintenance approach in boiler systems	✓	.	✓	✓	✓	.	.	.	.

3.	Goliada (2021)	To investigate inefficiencies in Spare Part Management Processes in Power Plants	.	.	.	.	.	.	.	.	✓
4.	Hlophe and Visser (2018)	To address risks associated with costing and scheduling of complex outage projects	.	.	✓	.	.	✓	.	.	.
5.	Singh and Pretorius (2017)	To ensure that inspections are planned in line with energy demands, to avoid doing mandatory inspections during times of high energy demand	.	.	.	.	.	✓	.	.	.
6.	Tsekoa (2017)	To fulfil the objectives of preventive maintenance, manage work orders, resources and to support decision making	.	.	✓	.	✓	.	.	.	.
7.	Brand et al. (2016)	To the appropriate times for interventions in Eskom power plants because the current measures were not adequate	.	.	✓	✓	.	✓	.	.	.
8.	Peach et al. (2016)	To investigate the use and importance of maintenance management performance measurements that focus specifically on human factors as part of the overall performance management system	.	.	✓	.	.	.	.	.	✓
9.	Petersen (2016)	To establish the the maturity level of the outage process of the Outage Management Department at Eskom	.	✓	.	.	.	.	.	.	.
10.	Sibanda (2016)	To improve the reliability of the boiler-coal processing plant in Eskom using Reliability Centred Maintenance principles	.	.	.	.	.	✓	.	✓	.
11.	Govender (2015)	To study theory and practical application of reliability engineering towards managing the maintenance		✓	✓	✓	.	.	.	.	.
12.	Ndjenja and Visser (2015)	To investigate strategy in the maintenance environment of power generation systems	✓	.	.	✓	✓	.	.	.	.
13.	Du Toit (2014)	To enable Predictive Maintenance using Semi-supervised Learning with Reg-D Transformer Data	.	.	.	✓	.	.	.	.	.
14.	Mwale and Davidson (2014)	Established an outage management plan that focused on annual planning and scheduling of outages, approving outage plans, performing scheduled outages, and closing out outages	.	.	✓	.	.	.	.	.	.

15.	Bembe (2013)	To investigate the management of condition-based monitoring and diagnostic technology to optimize timed-based maintenance of large turbo-generators	✓	.	✓	✓	.	.	.	.	.
16.	Mamabolo (2012)	To examine the effectiveness of planned maintenance in power stations	.	.	✓	✓	.	.	.	.	.
17.	Schlunz and Van Vuuren (2012)	The application of a computerized decision support model helped a South African national power system to address and solve real-life problems associated with generator maintenance scheduling (GMS)	.	.	.	.	✓	.	.	.	.
18.	Mutloane (2009)	Focused on employee engagement during the process of implementing work management which as key aspect of Total Productive Maintenance.	.	.	.	.	.	.	✓	.	.
19.	Hedges (2009)	Aimed at establishing the appropriate time a certain unit can be taken out of service for a particular interval	.	.	✓	.	✓	✓	.	.	.
20.	Badenhorst and Van Tonder (2004)	To evaluate factors that lead to human errors in South African government-own power plants	.	.	.	.	.	.	.	.	✓

Based on Table 2, it is apparent that Preventive Maintenance is the dominating maintenance approach in South African Power Plants. This is consistent with the finding of Mamabolo (2012) who stated that preventive maintenance dominates the maintenance efforts of the South African power plants.

Predictive Maintenance and Risk Based Maintenance were also showing a strong presence. These result are consistent with Sibanda (2016) who found that Eskom (90% owner of South African power plants) in the past ten years they have adopted reliability improvement initiatives, Risked Based Optimization approach and recently Risk Based Inspection (RBI). The one with least presence was Reliability Centred Maintenance (RCM). Consistent with the finding that there was no evidence of previous studies of RCM in South African power plants and this may be due to cost – a determining factor to using RCM (Sibanda, 2016). It is encouraging to see the less presence of Breakdown Maintenance. Since according to Govender (2015) for several years South African power plants relied on corrective maintenance. Du Toit, (2014) also confirmed that maintenance in South African power plants has evolved over the years. The worrying factor was to see the Differed Maintenance which is a destructive approach for complex systems. Eskom deferred their planned maintenance in order to meet the electricity demand leading to several break-downs of various power plant systems on daily basis, thereby causing power crisis leading to "load shedding" (Govender, 2015; Petersen, 2016).

6. Conclusion

The study identified and examined the maintenance strategies and techniques used in South African power plants. It was discovered that South African power plants use breakdown maintenance, preventive maintenance, predictive maintenance, computerized maintenance management system, risked based maintenance, total productive maintenance and human factors in maintenance. It is important to note that breakdown and preventive (time-based) maintenance were dominant maintenance approaches used in South African power plants. Hence, there is still a great challenge in South African power plants to ensure the reliability and availability of its assets to meet the electricity demands. This study made contribution in research by creating an agenda for discussion and debates within the power plant maintenance area, especially focusing on developing countries. It also discussed some of the challenges that are experienced when implementing these strategies. These challenges were related with leadership, training and constrained energy system that fails to match the social and economic demands. Like any other study, this study suffered limitations with regard to methodology and disappointingly absence of papers focusing directly on the use and review of the maintenance strategies. Many focused on the use and adoption of maintenance strategies. Future studies can focus on assessing the use of these maintenance strategies to reap maintenance benefits by either using quantitative, mathematical and qualitative methods.

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Biography

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