Mediating Role of Waste Management between Industry 4.0 and Sustainable Development

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Abstract

The purpose of the current study is to check the impact of waste management on the sustainable development of Industry 4.0. The current study targeted production managers in the industrial sector by using non-probability quota sampling technique. The data were collected through survey questionnaire from 257 respondents and analyzed through SPSS and PLS SEM. Findings of the current study revealed that the waste management plays a significant role to achieve sustainable development of Industry 4.0. Current study will help organizations for successful implementation of Industry 4.0 technologies, to manage their waste using the 3Rs approach and to get sustainable development. It will also help policymakers to deal with the waste for the attainment of sustainable development. The study reflects the cyber physical system (CPS) and niche theory important to achieve sustainable development in Industry 4.0. The current study is a novel addition to the literature regarding waste management. Moreover, it reflects that the "Industry 4.0 technologies" are predicted to be a game-changer in the industrial sector of a developing country.

Key words: Waste Management, Industry 4.0, 3Rs, Sustainable Development

Introduction

Industry 4.0 became famous after 2011 which is also considered as the fourth industrial revolution. Industrialization is an important process in production. For survival in this competitive age, the adoption of information technology has become the utmost requirement. Irrespective of the sector of the organization, in today's business world, organizations have the same view about the future, and they are no more surprised about future technologies. As they are aware of future technologies, so they wish to adopt industry 4.0 technologies because it increases their capabilities of product customization (Rüßmann et al., 2015). However, there is still high utilization of raw material, resources, energy, and information, which is less environmentally sustainable despite different advantages associated with Industry 4.0. Society is more concerned and aware of the challenges and risks associated with the environment (McWilliams, Parhankangas, Coupet, Welch, & Barnum, 2016). Hence current study will be an attempt to improve the conditions associated with this sector and improve economic, environmental, and social sustainability.

The focus of Industry 4.0 is to get maximum production and to achieve optimum profitability which creates problems for other dimensions like negative impact on the environment because of depletion of natural resources, inapt working conditions and not equal distribution of wealth. Consequently, the consumption patterns economically, environmentally and socially become unsustainable (Bonilla, Silva, Terra da Silva, Franco Gonçalves, & Sacomano, 2018). There are a few limitations in the production system that environmental system is not sustainable, and wastes are not reused, and productions are not produced on the renewable concept we should not ignore that our system can absorb these wastes. Therefore, we should focus on renewable natural resources instead of nonrenewable resources (Zhu, Zhang, & Sutton, 2015) because production belongs to the model which has “weak sustainability”, it misuses the balanced natural resources or Management of waste by producing such things which are environmentally disposable.

Although consumers understand natural resources are very important and they are available in limited quantity but still consumers are not controlling their consumption, which contrasts with sustainable consumption. The actual need for the products and goods is much lower as compared to the demand, hence there is a big gap between actual and sustainable consumption (Terlau & Hirsch, 2015). This situation will become the reason for the reduction in natural resources, destroying the environment and biodiversity (Seddon et al., 2016; Szeremlei & Magda, 2015). It is evident from the previous studies that environmental aspects are of great importance, at the same time modern technologies like Industry 4.0 will create better quality products (Xu, Xu, & Li, 2018). As the focus of Industry 4.0 is to increase production, improve quality and increase revenues, so there is less focus on environmental sustainability. This industrial revolution is facing some challenges like the non-availability of a skilled workforce, organizational protocols, and sustainable framework (Zéman, 2019). Industry 4.0 has entirely changed the methods and processes of production (Shpak, Odrekhivskyi, Doroshkevych, & Sroka, 2019; Shpak, Podolchak, Karkovska, & Sroka, 2019). The cost of production through Industry 4.0 technology is low but its direct impact on environmental sustainability cannot be measured easily (Smith, 2011). So, we need to know the impact of Industry 4.0 on society and environmental sustainability.

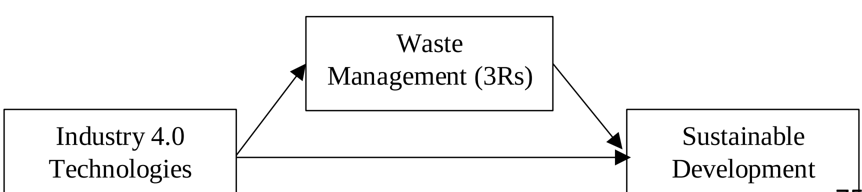
Here the need for environmental education for waste Management arises which is 3Rs i.e. reduce, reuse and recycle. It will help to control excessive production, use products more than one time and recycle these products. This can lead to the best utilization of resources and ultimately to sustainability. The purpose of the current study is to check the effect of environmental education on Industry 4.0 and sustainable development. The study will check the use of energy, raw material and other resources for production and waste generated because of these technologies and check whether the impact of these technologies is positive or negative. This study will also help policymakers and stakeholders to implement policies that are best suited to their industry. The study will also check sustainability from an economic, social, and environmental perspective.

Literature Review

Theoretical Foundation

The theoretical framework of the current study is based on two theories, one is niche theory (Hutchinson, 1961) and the other is the CPS (Park, Zheng, & Liu, 2012). The concept of the niche was introduced by G. Evelyn Hutchinson in 1957. This theory discussed the growing population and depletion of natural resources and species in the world. This also explains how competitors, populations and organisms respond to the depletion of resources. It will guide how to minimize the waste and do maximum utilization of available resources. While CPS explains how production systems are in a sequence, mass production and customized goods (Kagermann, Helbig, Hellinger, & Wahlster, 2013). This theory will deal with the production system and its impact on the environment (Lee, 2008). Hence, both the theories will back the current study as CPS is related to Industry 4.0 and niche will relate to sustainable development and waste management.

Figure 1. Theoretical Framework



Hypothesis Development

Industry 4.0 and Sustainable Development

The concept of Industry 4.0 is not very old, it was revealed in a Fair "Hannover" 2011 by a German Professor(Yang & Gu, 2021). Soon, this concept became very popular because of its features and benefits associated with it. This system allows machines to be interconnected which can be controlled virtually (Brettel, Friederichsen, Keller, & Rosenberg, 2017). It is also known as the Internet of Things (IoT) which connects machines with the internet or similar communication devices and can be helpful to exchange data with other devices. Due to the rapid population growth, the demand for the products is also increasing day by day (Hoornweg & Bhada-Tata, 2012). Customers demand more quality and customized products. Due to the increasing requirements, the competition has increased and become more difficult to cope up with the challenging and competitive environment without the adoption of Industry 4.0 technologies (Bonilla et al., 2018; Oztemel & Gursev, 2020). These technologies can increase the production capacity of producers and meet the reequipment of customers through their value-added services.

On the other hand, as industrialization is increasing, issues regarding sustainability also arise (Carley & Christie, 2017). Sustainable development is defined, as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Keeble, 1988). Sustainable development has three dimensions which are economic, social and environmental sustainability. This is also known as Tripple Bottom Line (TBL) approach. TBL argues that businesses focus on financial aspects which are also called economic aspects, but they should also measure the environmental and social impact of their business (Dao, Langella, & Carbo, 2011). This will create a positive impact on economic social and environmental conditions which will lead to the healthy and prosperous growth of a country. Thus, it is hypothesized:

H1: There is a positive relationship of Industry 4.0 on Sustainable Development

Industry 4.0 and Waste Management

As production will increase, the amount of waste generated by the manufacturing industries will also be increased (Ohno & Bodek, 2019). This is also one of the distinguishing features of Industry 4.0 that these technologies generate less waste as compared to the traditional technologies (Frank, Dalenogare, & Ayala, 2019). There is still a great need for waste management in the country which can be done with the help of 3Rs which are reduced, reuse and recycle. First, the adoption of Industry 4.0 technologies is required which will help to reduce the waste generation of waste. Second, the concept of reuse is about the use of products more than once which is possible if items are discouraged and reusable products are preferred, it will also help to reduce the cost (van Straten, Dankelman, van der Eijk, & Horeman, 2021). Third, the products after use should be recycled and converted into some other useful thing instead of buying new products every time (Mohr, Webb, & Harris, 2001). Within the industry also, all 3Rs can be performed with respect to the manufacturer. If the industry works on the 3Rs of waste management, the industry can increase its productivity and profitability (Ghisellini, Cialani, & Ulgiati, 2016). Hence, we can hypothesize that:

H2: There is a positive relationship of Industry 4.0 on Waste Management

Waste Management and Sustainable Development

Pakistan is generating around 48.5 Mill ton of solid waste every year (Administration, 2021). This is a very high volume of solid waste, which is a big challenge for sustainable development. This waste is not generated by the industry only, but it also includes domestic waste. This high volume of waste can only be controlled by using the 3Rs approach of waste management (Huang et al., 2018). Waste damages the esthetic beauty of nature, it also becomes the reason for pollution which causes many diseases (Beard & Green, 1994). All the 3Rs are equally important for waste management to improve the esthetic beauty and prevention from different diseases which are caused by the waste. It is evident from the available literature that waste management is very important to attain real sustainable development not only in the industry but also for society and our daily life (Hopwood, Mellor, & O'Brien, 2005; Kemp, Loorbach, & Rotmans, 2007). Hence, we hypothesize that:

H3: There is a positive relationship between Waste Management and Sustainable Development

Mediating Role of Waste Management

As production is increasing, the demand for material is also increasing. Waste management can be helpful to reduce the volume of waste generation and its effect on health and environmental pollution (Tchobanoglous & Kreith, 2002). There are different types of waste in terms of their composition and nature therefore these will be treated differently, but the main concept of 3Rs will remain the same for all types of waste (Abdel-Shafy & Mansour, 2018). It is the corporate social responsibility (CSR) of every organization and individual to control waste (Zhang, Jeong, Olson, & Evans, 2020). When customers are aware of the CSR regarding the efforts of a company, they become more loyal to the company and consequently company's sustainable performance improves (Albus & Ro, 2017; Chaudary, Zahid, Shahid, Khan, & Azar, 2016). Researchers claimed that by using eco-friendly campaigns, a positive image of the company is built which can influence the customer due to its sustainable development initiatives (Chaudary et al., 2016). Hence, we hypothesize that:

H4: Waste management has mediating effect of the Industry 4.0 Technologies on sustainable development.

Methods

Sample design and the data collection

The population of the current study was six manufacturing sectors of Punjab, Pakistan. Data were collected from textile, paper products, plastic, surgical, glass & ceramics and chemical industries using a survey questionnaire. Non-probability quota sampling was adopted for the collection of data. We distributed 100 questionnaires among each targeted industries (Textile, Plastic, Paper products, Surgical, Glass & Ceramics and Chemicals). A total 600 hundered questionnaires were distributed out of which 283 questionnaires received at the response rate of 47.16% and 257 questionnairs were screened out and considered eligible for data analysis at effective response rate of 42.83%.

Table 1 gives a comprehensive summary of the demographics of respondents and the organization that was part of the research for data collection. Most of the respondents were male 191 (74.3%) and a few were female 66 (25.7%) out of a total of 257 respondents. Majority of the respondents 127 (49.4%) were between the age group of 31-50 years, whereas 114 (44.4%) were above the age of 50 years and only 16 (6.2%) were below the age of 30 years. Companies with less than 100 employees are 114 (44.4%), while with 100 to 200 employees were 99 (38.5%) and with 201 or more workers were 44 (17.1%). Further, 67 (26.1%) respondents were from the textile sector, 47 (18.3%) respondents were from the paper products manufacturing company, 42 (16.3%) respondents were from the glass and ceramics sector, 40 (15.6%) respondents were from chemicals, 31 (12.1%) respondents were from plastic industry and 30 (11.7%) respondents were from the surgical sector.

Table1: Demographics

Demographics	Categories	Frequency (N = 257)	Percentage
Gender	Male	191	74.3
	Female	66	25.7
Age	30 or below	16	6.2
	31-50	127	49.4
	Above 50	114	44.4
Company Size	Less than 100 employees	114	44.4
	100 to 200 employees	99	38.5
	201 and above	44	17.1
Company Sector	Textile	67	26.1
	Paper Products	47	18.3
	Plastic	31	12.1
	Surgical	30	11.7
	Glass and Ceramics	42	16.3
	Chemicals	40	15.6

Questionnaire and pre-test

The questionnaire is based on 46 items including demographics. The first section of the questionnaire was based on 4 questions regarding the demographics of the respondent and the industry. The second part of the questionnaire was based on 10 items regarding the "Industry 4.0" technologies was adopted form (Industry, 2016) which was based on 5 points Likert scale 1 is considered for "not used" to 5 is considered for "fully adopted" which was treated to check the level of adoption of these different technologies in that industry. The third portion of the questionnaire was based on 14 items regarding the "waste management" or (3Rs) was adapted from (Barr, Gilg, & Ford, 2001) which was based on 5 points Likert scale, where 1 will be considered for "strongly disagree" to 5 for "strongly agree". The last part of the questionnaire was based on 18 items regrading "sustainable development" was adapted from (Gericke, Boeve-de Pauw, Berglund, & Olsson, 2019) which was based on 5 points Likert scale of 1 for "strongly disagree" to 5 for "strongly agree". Minor modifications were done in the language of questions to make it easier and understandable in the context of the targeted industry. Construct validity was performed under the guidance of expert academicians and changes were incorporated ad per their guidance. As different parts of scale were already used in various studies separately hence the pre-test was not essential.

Results

Smart PLS 3 was used for analysis and testing of hypothesis through PLS-SEM. Smart PLS is widely used in business studies for analysis because it is known as the modern technique for assessment in this field (Rasoolimanesh, Ali, & Jaafar, 2018). The study intends to foresee and discuss the current theory beached by different variables mentioned in the current study. Another reason to select PLS-SEM for analysis is that the requirement regarding the data normality and sample size is comparatively easier as compared to the Amos (Hair Jr, Hult, Ringle, & Sarstedt, 2016). This is the reason for the assessment of the model, PLS-SEM is assumed more convenient (Hair Jr et al., 2016; Naz, Jamshed, Nisar, & Nasir, 2021). PLS algorithms and bootstrapping were run to check the internal consistency reliability, validity of constructs, hypotheses test, path coefficients and significance level (Rasoolimanesh et al., 2018).

Measurement Model Assessment

The measurement model was run and factor loading, convergent validity, competitive reliability were also checked. As shown in Table 2 and Figure 2. that the factor loadings of most of the items were above the suggested value i.e. 0.60, excluding value of a few items. Items with a value less than 0.50 were deleted. The composite reliability (CR) values of all latent reflective models are above the suggested threshold value of 0.7. The instrument is also considered reliable because all the values of Cronbach alpha (α) are more than the suggested limit. A value less than 0.60 is considered poor, more than 0.70 is considered good and more than 0.80 is considered good (Hair, Celsi, Ortinau, & Bush, 2010). All the values of alpha re above 0.80. Likewise, all the values of average variance extract (AVE) are above the threshold value i.e. 0.50 (Hair Jr et al., 2016).

Table 2: Convergent Validity

Constructs	Items	Loading	Alpha	CR	AVE
Waste Management	EE1	0.78	0.878	0.904	0.517
	EE10	0.839			
	EE11	0.738			
	EE12	0.79			
	EE13	0.528			
	EE14	0.685			
	EE2	0.504			
	EE8	0.717			
	EE9	0.808			
Industry 4.0	Ind1	0.842	0.87	0.905	0.619
	Ind10	0.501			
	Ind2	0.854			

	Ind3	0.859			
	Ind4	0.837			
	Ind5	0.765			
Sustainable Development	SD10	0.604	0.918	0.919	0.647
	SD11	0.567			
	SD12	0.561			
	SD13	0.741			
	SD14	0.762			
	SD15	0.735			
	SD16	0.676			
	SD17	0.805			
	SD18	0.731			
	SD3	0.599			
	SD4	0.674			
	SD5	0.644			
	SD6	0.589			
	SD7	0.577			
	SD8	0.559			

Discriminant validity

Two variables should not be highly correlated with each other, this is called discriminant validity. There are two methods to check the discriminant validity, one is Heterotrait-Monotrait Ratio (HTMT) (Henseler, Ringle, & Sarstedt, 2015) and the other is the Fornell Lacker criterion and other is Fornell & Larcker, 1981). In the current study, we have used the HTMT ratio which is reported in Table 3, values are less than the suggested limit of 0.90 which shows that there is no discriminant validity in the variables (Gold, Malhotra, & Segars, 2001). Another researcher says that the value of the HTMT ratio should be less than 0.85 (Kline, 2015).

Table 3: Discriminant Validity (HTMT Ratio)

	Waste Management	**Industry 4.0**	**Sustainable Development**
Waste Management			
Industry 4.0	0.768		
Sustainable Development	0.458	0.428	

Structural Model Assessment

After checking reliability and validity of the model through measurement model, the structural modeling was done to test the hypothesis. With the collected data, bootstrapping was performed using Smart PLS to check the direct and indirect relationships shown in Figure 3 and Table 4 (Ringle, Wende, & Will, 2005). Industry 4.0 has positive and significant relationship with sustainable development (β = 0.198, t = 2.349; LL = 0.076, UL = 0.35) therefore we can say, H1 is supported. Industry 4.0 has significant and positive relationship with waste management (β = 0.674, t = 15.721; LL = 0.603, UL = 0.741) therefore H2 is supported. Waste management has significant and positive relationship with sustainable development (β = 0.372, t = 4.637; LL = 0.227, UL = 0.49) hence, H3 is supported. Industry 4.0 has significant and positive indirect relationship with sustainable development through waste management (β = 0.251, t = 4.61; LL = 0.16, UL = 0.339) thus, H4 is also considered to be supported.

Figure 2: Measurement Model Assessment

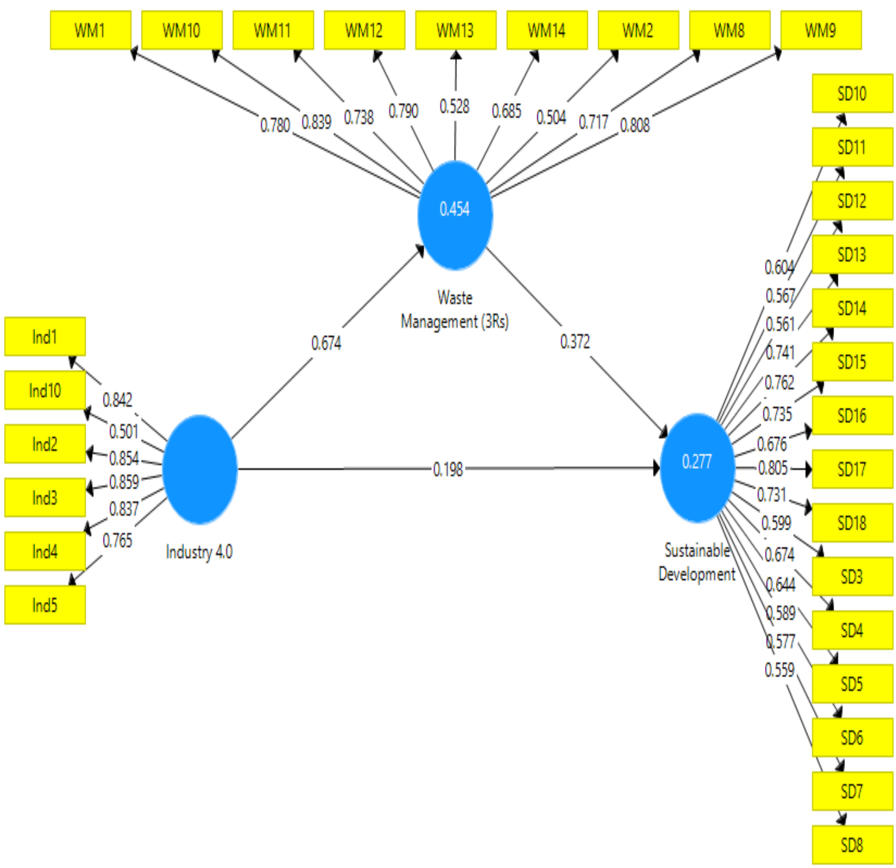


Figure 3: Structural Model Assessment

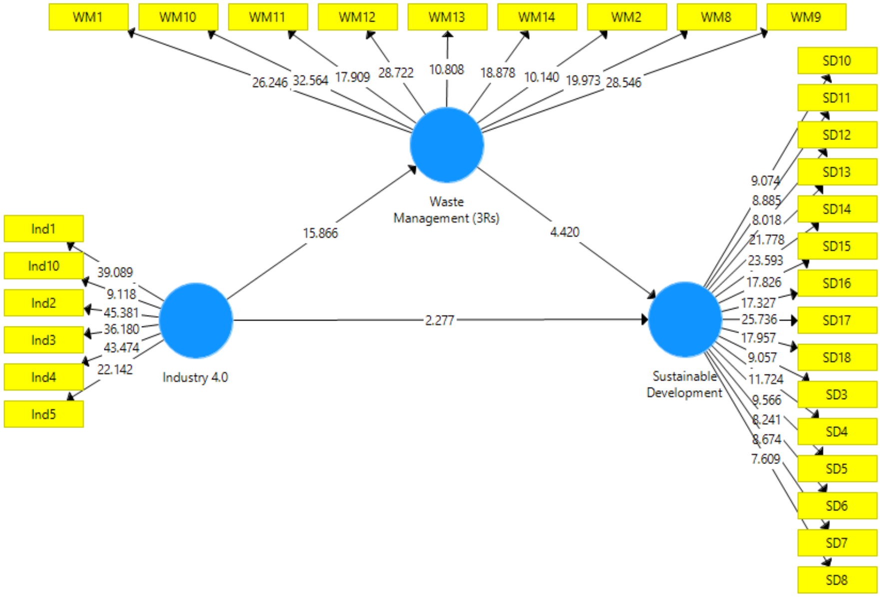


Table 4: Path Analysis

	Relationships	Beta	S.D.	T-Values	*P* Values	L.L.	U.L.	Decision
H1	Industry 4.0 -> Sustainable Development	0.198	0.084	2.349	0.01	0.076	0.35	Supported
H2	Industry 4.0 -> Waste Management	0.674	0.043	15.721	0	0.603	0.741	Supported
H3	Waste Management -> Sustainable Development	0.372	0.08	4.637	0	0.227	0.49	Supported
H4	Industry 4.0 -> Waste Management -> Sustainable Development	0.251	0.054	4.61	0	0.16	0.339	Supported

Conclusions

With the industrial revolution, the use of toxic chemicals and discharge of pollutants increases (Islam & Tanaka, 2004) which leads to environmental and social issues. Economically, industrialization is good, as it gives more profits to the organization and better growth to a country. But the growth of the industry is not good for the environmental and social perspective if these are being ignored by an organization. To achieve sustainable development, it is important to consider all sustainable development elements equally important. It can only be possible if an organization has a sense of responsibility and give equal importance to all three elements of sustainable development. It will also help to create a positive image of the organization among customers and in society. This positive image will become a reason to bring more orders for the organization and will earn more profits. In other words, it can also be said that the expenses incurred on the economic, social and environmental pillars are not the expenses, this is actually the investment that gives a return after a few years.

All 3Rs are equally important for waste management, first R is for Reduce which explains that excessive production should be controlled and the manufacturing should be done as per requirement only. The second R is for recycling, which explains that the products or waste material should be recycled and converted into some other usable product. The third R is for Reuse, which highlights the importance of using products time and again. In short, waste management is very important for the optimum utilization of raw materials and other products. The application of 3Rs is not only encouraging less consumption of resources but it is also giving financial benefits, which consequently leads towards sustainability. This sustainability achieved through waste management helps to get sustainable development. Therefore, the current study will be helpful for the researchers as well as for the policymakers to formulate policies of waste management keeping interview sustainable development. It is also suggested that natural raw materials should be used instead of synthetic raw materials to achieve sustainability.

Theoretical and practical implications of the study

Results of this study predict many practical and theoretical implications for researchers, policymakers and practitioners. Study theoretically contributes to CPS and niche theories because of its relevance with both theories. Since the research was conducted in the Pakistani context which is an emerging economy, therefore the current study is an opportunity to check the phenomenon in the developing country. The findings of this study discovered that Industry 4.0 has a significant and positive relationship with sustainable development. Further, waste management significantly and positively mediates between Industry 4.0 and sustainable development. Moreover, the study has contributed to filling the gap in the existing body of knowledge in the literature.

Limitations and future directions

The current study is conducted in Pakistan, which is a developing country, although the data were collected from different industrial sectors and different cities, the study has limitations related to its geographical location which is one country. To delimit this issue and to increase the generalizability of the study, similar research should be conducted in other countries and comparative studies with other countries can also be conducted in the future. Further, this study did not measure the volume of waste generated from different types of industries and similarly, intentions of people to reduce waste were not measured. Further studies can also measure the intentions of industrialists for waste management.

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