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The Power of Six Sigma Tool for Defect Reduction: Real Case from the Industrial Sector in Saudi Arabia

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ABSTRACT

Achieving the highest levels of quality is the main target for all companies in all sectors. The aspect of the highest quality differs from organization to another. It could mean exceeding customers` expectations, speed of delivery, feasibility, product quality, reduce total cost, or minimizing the total defects in processes/services. Six Sigma is practical work to get error-free business performance. One of the Six Sigma's distinctive approaches to process and quality improvement is DAMIC (define, measure, analyze, improve and control). DAMIC model refers to five interconnected stages that systematically help organizations to solve problems and improve their processes. This work illustrated applying DAMIC model in the industrial sector. The data of this case obtained from a leading manufacturing company based on Jeddah, Kingdom of Saudi Arabia. Statistical analysis has been applied using EViews7 and SPSS25. A Cause-and-Effect diagram has been proposed. Whereas correction and improvement actions have been suggested by the quality team of the company.

Keywords: Six Sigma; DMAIC; Quality improvement; Cause-and-effect diagram, Defect reduction.

1. INTRODUCTION

Globalization makes the competition an arduous task that requires continuous improvement and quality enhancement. Organizations try their best not only to reach the customers` expectations but to also surpass those expectations. In this context, Six Sigma has become a vital approach for those organizations. Six Sigma provides effective statistical tools and techniques which help dispel variability and scale back waste in processes [1-3]. Six Sigma enables the organizations to maintain the highest quality by monitoring the reasons for quality defects then eliminating these root causes with the goal of approaching no defects [4-5].

In 1980, Motorola was trying to achieve the quality targets for their manufactured products to be in the first line. Hence, Motorola developed the Six Sigma approach [1] to move from the conventional approach of characterizing defects per thousand opportunities to measuring defects per million opportunities and to identifying root causes, solutions, and need changes. Six Sigma approach has been developed to be a broader, companywide philosophy instead of a method improvement methodology [4], [6]. Currently, Six Sigma has become the golden standard of improvement action used by many companies to maintain the highest level of quality [7-9]. Six sigma implementation fields include, but not limited to: improvement of product quality, improvement of processes quality, increasing customers` satisfaction, and shortening cycle times [9-12]. By using Six Sigma approach, companies identify quality errors as well as suggest actions that reduce these errors to the minimum practically achievable values. Reducing quality errors to be near zero requires updating the analysis and the improvement actions continuously [7], [13]. So, as reducing the quality errors is the main target for any companies, implementing DAMIC model is an effective tool to achieve the high quality.

This paper illustrates the implementation of DAMIC model to discover the quality deficiency causes in GEDAC Company. Moreover, based on Cause-and-Effect diagram, some correction and improvement actions have been suggested by the quality team of the company.

2. MATERIALS AND METHODS

The methodology of this research is divided into two major sections namely, problem formulation, and the implementation of the DAMIC application. The data collected from a real project from a leading manufacturing company based on Jeddah, Kingdom of Saudi Arabia. The collected data were analysed to be used in suggesting the improvement and correction actions to reach zero error product defect. The research methodology in our case is illustrated in Figure 1.

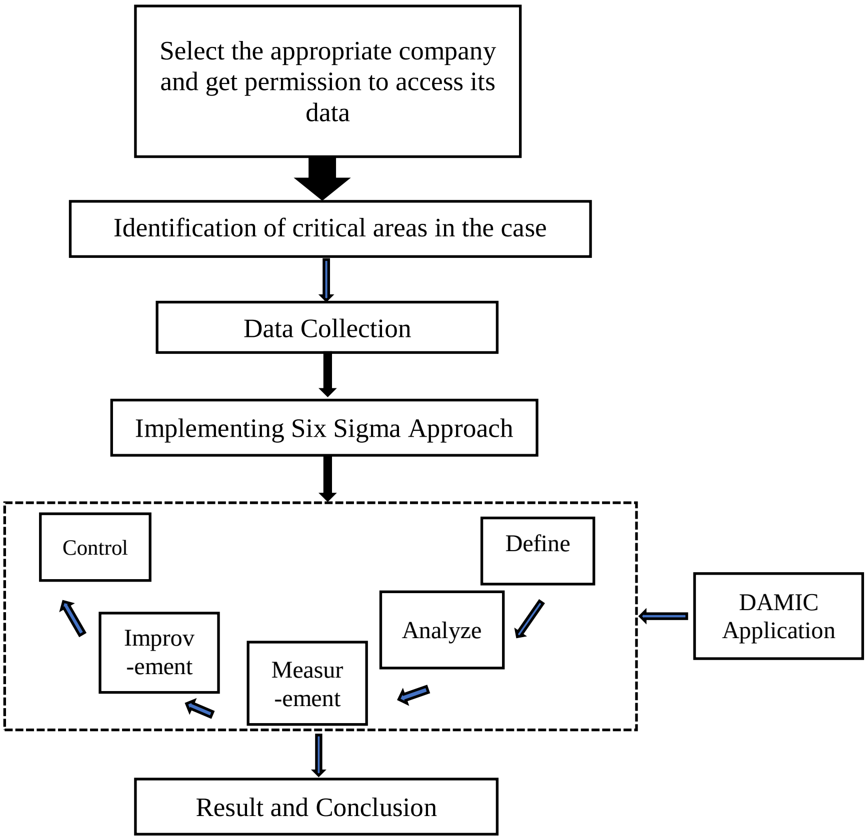

Figure 1. Methodology adopted for this Research.

3. INTRODUCTION TO THE INDUSTRIAL CASE AND PROBLEM FORMULATION

GEDAC is a company committed to be the pioneer on power distribution equipment, solutions and services in the Middle East, design, manufacture, and servicing. The 21000 m^2 plant has been in service from 1978 and has supported international standards such as ANSI (American National Standards Institute) / NEMA (National Electrical

Manufacturers Association) and ISO (International Organization for Standardization) in manufacturing and assembling customized turnkey solutions for power distribution and protection and after-sales services in low and medium voltage. The aim of GEDAC Company is that products and services that fulfill customer requirements should be developed, produced, and delivered. To pursue this aim, GEDAC Company has implemented a quality system based on ISO-9001, 14001 & OHSAS 18001. A study was conducted in the selected unit to reduce the dismissal with DAMIC study by considering all these facts

4. IMPLEMENTATION OF DAMIC APPLICATION

4.1 Define phase

The collected data for the medium voltage equipment obtained during 31 months. The collected data are 31 observations. The quality team chooses the variables in line with their quality goals. The formulation of the quality team members is essential step. The team members for the project include Senior Managers, Planers, and Repair Managers. Senior Engineers and one machine operator will be responsible for quality control. The Senior Production Manager serves as the team leader.

4.2 Analyse phase

In this phase, the variables have been grouped into a smaller set of constructs without losing much information from the original data. EViews7 and SPSS 25 were used for factor analysis. To apply factor analysis, the data needed to be analysed by subtracting the mean for all values and divided them by the standard deviation of those values [14]. By this way, the effect of the measurement scale is removed, and the variables are treated equally in the analysis, Table 1 represents the calculated Eigenvalues Summary. Furthermore, verification has been done for factor analysis through the examination of the correlation matrix of the variables. There is a high number of correlation coefficients between variables which are higher than 0.5. Those variables will also be highly correlated with the same factor. Principal factors estimation has been performed with retaining factors based on Kaiser-Guttman, the initial commonalities based on the squared multiple correlations [15].

Table 2. Eigenvalues summary

Eigenvalues Summary
Eigenvalues of the Observed Matrix
Factor: DATABASE
Time: 18:39

Eigenvalues: (Sum = 46, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	7.006008	1.222105	0.1523	7.006008	0.1523
2	5.783903	0.860052	0.1257	12.78991	0.2780
3	4.923851	1.349430	0.1070	17.71376	0.3851
4	3.574421	0.427114	0.0777	21.28818	0.4628
5	3.147307	0.338290	0.0684	24.43549	0.5312
6	2.809017	0.233152	0.0611	27.24451	0.5923
7	2.575865	0.510010	0.0560	29.82037	0.6483
8	2.065855	0.152560	0.0449	31.88623	0.6932
9	1.913296	0.060131	0.0416	33.79952	0.7348
10	1.853164	0.215592	0.0403	35.65269	0.7751
11	1.637572	0.138878	0.0356	37.29026	0.8107
12	1.498694	0.295038	0.0326	38.78895	0.8432
13	1.203656	0.104071	0.0262	39.99261	0.8694
14	1.099585	0.124387	0.0239	41.09219	0.8933
15	0.975198	0.093134	0.0212	42.06739	0.9145
16	0.882064	0.115095	0.0192	42.94945	0.9337
17	0.766968	0.214980	0.0167	43.71642	0.9504
18	0.551989	0.157494	0.0120	44.26841	0.9624
19	0.394494	0.016362	0.0086	44.66290	0.9709
20	0.378132	0.046287	0.0082	45.04104	0.9792

The principal factors estimation is the most used method. At the same time with 31 observations, the potential maximum likelihood and generalized least squares cannot be applied due to the near singular matrix. Factor (Fj) can be expressed as: [3], [16]:

$$Fj = cj1*t1 + cj2*t2 + cj3*t3 + cj4*t4 + \ldots + cj45*pn\text{-}1 + cj46*pn \tag{1}$$

Where, Fj is factor scores and cji isfa ctor coefficients scores of the model, t1, t2, t3, … pn-1, pn: observed variables.

The main outcome of the factor analysis represented in Kaiser's diagram, Table 2 shows 14 factors with eigenvalues which are higher than 1 and an absorbed variance of 89.33%.

Table 2. Kaiser's diagram shows the factors and main correlated variables

Factor	Variable	Mean of errors	Factor Loading	Definition	Factor/Construct Name	Absorbed Variance %
F1	t7	1.06	0.42	Missing Barriers	Wrong Markings	15.23
	t9	2.16	0.49	Wrong Ferrules marking		
	t17	0.77	0.48	Phase Marking missing		
F2	t4	25.16	0.47	Missing Material	Missing Material	12.57
	t10	2.40	0.48	Terminal Block Numbering not done		
	t18	3.84	0.39	Name Plates missing		
F3	t3	3.80	0.37	Material Short	Material Short	10.71
	t22	0.93	0.33	Impromer Mounting of Components		
	e6	0.38	0.38	Not required		
	e10	0.71	0.38	Follows Proposals. Different Rating in Single Line Diagram		
F4	t2	2.53	0.39	Drawings Mistakes - Mechanical	Mechanical Problem	7.77
	t21	15.27	0.36	Mechanical Problem		
	e3	120.24	0.29	Request by Procurement		
	m1	0.95	0.36	Space Problem		
	p2	11.26	0.44	Mechanical Drawings Problem		
	p3	0.93	0.31	Material Discrepancy - Main Supplier		
F5	t11	0.26	0.47	Extra Fuse to be removed	Material Short (non allocated)	6.84
	t16	1.45	0.36	Wrong Components mounting		
	t20	0.03	0.38	Panels not cleaned		
	p4	286.84	0.47	Material Short (non allocated)		
F6	t5	3.33	0.55	Wrong Component selection	Defective/Wrong Material	6.11
	t19	0.61	0.67	Defective Material		
F7	t8	0.52	0.60	Ferrules are not heat shrink	Missing Wiring	5.60
	t15	10.76	0.49	Missing Wiring		
F8	e8	7.06	0.55	Wrong allocation	Wrong Electrical allocation	4.49
	e9	4.80	0.59	Due to used of old Stock		
	p1	37.29	0.34	Electrical Drawings problem		
F9	t14	2.03	0.32	Extra Wires to be removed	Material Short-time arrangement	4.16
	e11	4.54	0.66	Material Short-time arrangement		
	m2	0.74	0.46	Damage Components		
F10	t6	0.22	0.59	Neutral splice missing	Testing Feedback	4.03
	e12	3.25	0.59	Testing Feedback		
	p5	10.32	0.39	Short allocation		
F11	e3	120.24	0.41	Request by Procurement	Wrong Purchased Material	3.56
	e14	10.16	0.71	Wrong Material from Main Supplier		
F12	t1	48.21	0.34	Drawings Mistakes - Electrical	Wrong Wiring	3.25
	t13	6.90	0.64	Wring Wiring		
	t14	2.03	0.31	Extra Wires to be removed		
	e7	132.27	0.41	Missed Allocation		
F13	e5	4.09	0.46	Already included in Part Numbers	Short Material Allocation	2.62
	p6	3.77	0.41	Wrong Material Allocation		
	p7	47.91	0.48	Short Material Allocation		
	p8	28.24	0.47	Missed Allocation		
F14	t16	1.45	0.24	Wrong Components mounting	Extra Material Allocation	2.39
	e1	114.41	0.61	Extra Material Allocation		
	e2	64.25	0.69	Request by Project Management		
					Total Absorbed Variance	89.33

Goodness-of-fit testing is an important element of any analysis because the model represents a general set of hypotheses about the ecological and observation processes that generated the data. Thus, if the model "fits" in some statistical or scientific sense, then It could conclude that the model appears adequate [17]. Table 3 represents Goodness of fit of the factor model adjusted results. The table shows that the parsimony ratio= 0.46 which indicates poor result, as much closer to one shows a better fit. The table also shows the Mean Square Residual (RMSR) = 0.19 which represents a good adjustment. The Normed Fit Index (NFI) at 0.37 represents a poor result, as much closer to one shows a better fit.

After performing the Orthogonal and Varimax rotation, the following factor loadings have been obtained. Table 4 represents the rotated factor loadings. The new five factors and the related variables with the higher factor identify the new factors with the name of the related business processes. The model is be re-calibrated until reaching the acceptable results. Next, the factor scores coefficients based on the exact coefficients type and the regression method are re-calibrate. Table 5 represents the Goodness-of-fit Summary for the new calibrated factor model and Table 6 illustrates the Goodness-of-fit Summary for the new calibrated factor model. It shows that, the parsimony ratio = 0.34 as well as RMSR = 0.06 which showed good adjustment. As well as errors among the observed matrix and the reproduced one is very small. Also, NFI= 0.75 which showed a satisfied result.

4.3 Measure phase

Measurement is the second phase For DAMIC Cycle. Variables and the associated data have been collected and observed by the testing engineering and production department as well as customers` complaint report by the project management department in the company.

4.4 Improvement phase

Improving product /service in a project means acting against quality deficiency causes. Figure 2 represents the cause-and-effect diagram analyses made during the brainstorming section.

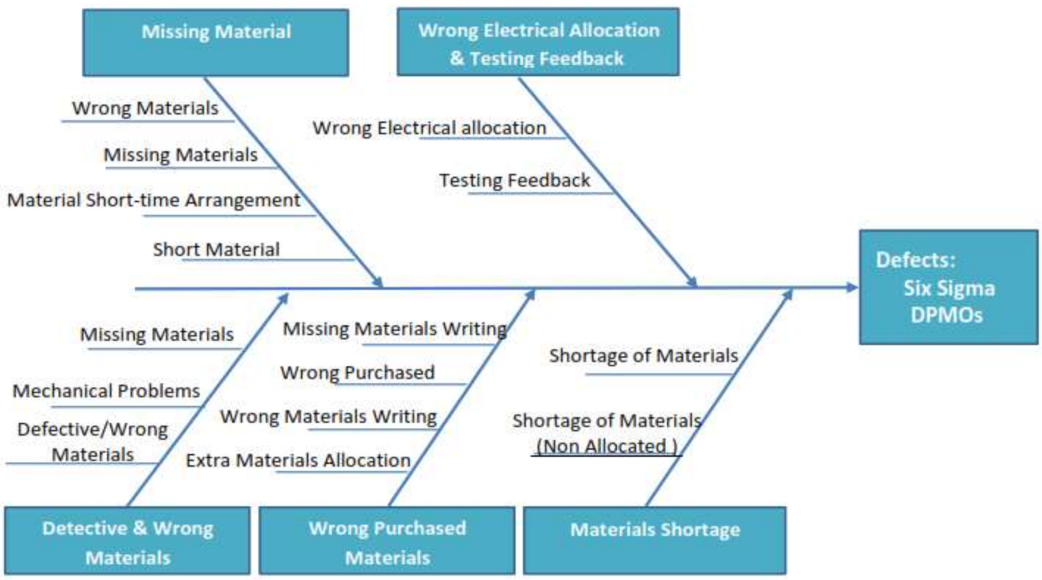

Figure 2. The proposed Cause and Effect Diagram

One of the simplest tools to implement the Six Sigma approach is the cause-and-effect diagram. After a brain storming session with both the quality team and the people involved in the process, the cause-and-effect diagram was produced. Making brainstorming among the team associated with quality is the most powerful tool for quality improvement [18].

The quality team would raise the suggested improvement steps towards the top management after the brainstorming sessions. It is to obtain the approval of the top management and therefore all resources needed for the improvement are viable.

Table 3. The Goodness of fit of the factor model

Goodness-of-fit Summary
Factor: DATABASE
Date: 10/02/15 Time: 18:41

	Model	Independence	Saturated
Parameters	599	46	1081
Degrees-of-freedom	482	1035	---
Parsimony ratio	0.465700	1.000000	---
Absolute Fit Indices			
	Model	Independence	Saturated
Discrepancy	37.70676	60.02702	0.000000
Root mean sq. resid. (RMSR)	0.190871	0.240826	0.000000
Incremental Fit Indices			
	Model		
Bollen Relative (RFI)	-0.348857		
Bentler-Bonnet Normed (NFI)	0.371837		

Table 4. Rotated Factor Loadings

Rotation Method: Orthogonal Varimax
Factor: DATABASE3
Date: 10/02/15 Time: 18:10
Initial loadings: Unrotated
Convergence achieved after 54 iterations

Rotated loadings: L * inv(T)'

	F1	F2	F3	F4	F5
SF1	-0.010535	-0.357709	0.083971	0.133042	0.233296
SF2	0.128573	0.311494	0.111397	-0.057210	-0.549882
SF3	-0.064999	-0.060744	-0.706790	0.010076	-0.080188
SF4	0.235731	-0.230938	-0.092473	-0.145850	-0.372181
SF5	-0.065503	-0.109246	0.672044	-0.013798	-0.101367
SF6	0.171401	0.148114	0.052402	-0.090863	0.576111
SF7	-0.225006	-0.023158	-0.016550	0.480331	0.211392
SF8	0.659283	-0.141008	0.022051	0.136123	-0.043516
SF9	-0.251358	0.375850	0.092782	0.212616	-0.092747
SF10	0.483973	0.295293	-0.012230	-0.011130	0.157733
SF11	0.222646	0.024989	-0.033912	0.637486	-0.043713
SF12	0.185463	0.158293	0.029146	-0.324651	0.260975
SF13	-0.050485	0.635699	-0.062009	0.008744	0.030795
SF14	0.143829	0.073801	0.051815	0.377846	-0.071032

Table 5. The re-calibrated factors

Factor	Variable	Factor Loading	Definition	Factor/Construct Name	Absorbed Variance %
F1	SF8	0.059	Wrong Electrical Allocation	Wrong Electrical Allocation & Testing Feedback	13.8
	SF10	0.484	Testing Feedback		
F2	SF1	-0.357	Wrong Markings	Missing Material	11.95
	SF2	0.311	Missing Material		
	SF9	0.375	Material Short-time arrangement		
	SF13	0.635	Short Material Allocation		
F3	SF3	-0.706	Material Short	Material Short	10.77
	SF5	0.672	Material Short (non allocated)		
F4	SF7	0.48	Missing Wiring	Wrong Purchased Material	9.63
	SF11	0.637	Wrong Purchased Material		
	SF12	-0.324	Wrong Wiring		
	SF14	0.377	Extra Material Allocation		
F5	SF2	-0.549	Missing Material	Defective/Wiring Material	8.47
	SF4	-0.372	Mechanical Problem		
	SF6	0.576	Defective/Wrong Material		
				Total Absorbed Variance	42.73

Table 6. The re-calibrated Goodness of fit summary

Goodness-of-fit Summary
Factor: DATABASE3
Date: 10/02/15 Time: 18:17

	Model	Independence	Saturated
Parameters	74	14	105
Degrees-of-freedom	31	91	---
Parsimony ratio	0.340659	1.000000	---

Absolute Fit Indices

	Model	Independence	Saturated
Discrepancy	0.360388	1.463989	0.000000
Root mean sq. resid. (RMSR)	0.062931	0.126838	0.000000

Incremental Fit Indices

	Model
Bollen Relative (RFI)	0.277375
Bentler-Bonnet Normed (NFI)	0.753831

Based on the cause-and-effect diagram, the quality team illustrated that the quality deficiency causes occur because of; wrong material, missing materials, material short-time arrangement, short material, mechanical Problems, defective/wrong materials, wrong electrical allocation, testing feedback, missing material writing, wrong purchased, wrong material writing, extra material allocation, extra material allocation and shortage of materials. Therefore, the quality team suggested some improvement actions against these causes as illustrated in Table 7.

Table 7. Cause solution matrix

No.	Cause	Suggested Improvement Actions
1-	Wrong Material	Data sheets should be defined by production department and followed by purchasing and quality control dept. through their Accredited procedures.
2-	Missing Materials	A minimum stock plan should be designed by planning dept. and followed by stores and purchasing departments.
3-	Material short-time arrangement	Production plan should be carried out by stores.
4-	Short Material	Material Minimum stock plan to be followed by noticed departments.
5-	Mechanical Problems	Showed be detailed studied to suggest improvements.
6-	Defective /wrong materials	Inspection sheet should by specified and followed by quality control.
7-	Wrong electrical allocation	Improve workplace organization.
8-	Testing feedback	Test feedback sheet should be cycled to notice departments.
9-	Missing Material writing	Material list should be revised and approved by production dept.
10-	Wrong purchased	Purchasing department must follow material approved data sheet.
11-	Wrong material writing	Material list should be revised and approved by production department.
12-	Extra material allocation	Production plan should be followed by stores and handling department.
13-	Shortage of materials	Material Minimum stock plan to be followed by noticed depts.
14-	Shortage of materials (Non-Allocated)	Production plan should be followed by stores and handling department.

4.3 Control phase

Steps to control the problems already addressed by the quality team and accepted by the top management are taken during the monitoring process. Six Sigma's greatest challenge is the durability of the outcomes obtained. Often, it is incredibly difficult to sustain the results because of numerous factors, including the change of staff, promotion/transfer of people employed in this process, shifting individual attention to other process problems elsewhere in the company, and a lack of responsibility for new workers in the process [19].

The consistency of the results demands that improved methods be standardized and that processes for tracking the main results be developed. It also needs sensitization among the workers who carry out the research. Standardization of the solutions was achieved by modifying the process procedures required that were part of the organization's quality program. The quality plans have been updated according to the solutions.

5. MANAGERIAL IMPLICATIONS

In the past, isolated efforts have been made to implement initiatives such as statistical process monitoring, qualitative cycles, continuous improvement programs and self-sustaining. No systematic efforts were made in the implementation of these initiatives to identify opportunities for improvement in line with business priorities and customer requirements. It made the importance of these programs, with the highest priority addressed, less apparent in the company than in Six Sigma projects where customer voice has been developed. Owing to its performance in this project, the management agreed to use the Six Sigma Approach for all potential improvements. A core group of all the functional heads of the company was created to oversee the Six Sigma initiatives. The department was responsible for project design and project management. The team was also informed of all issues relevant to the implementation of further action. Six Sigma has been implemented to solve any form of problem in the process as a method within the enterprise. The goal of the management was to bring about a cultural change in this organization through the participation of everyone in this movement of excellence.

6. CONCLUSIONS

DAMIC model have been implemented in GEDAC Company, which is a leading manufacturing company based on Jeddah, Kingdom of Saudi Arabia. The main target is to get error-free business performance. The implementation of DAMIC model has been a major challenge for the following reasons:

- Despite the employees' busy daily schedule, it was very difficult to attend training.
- It was not easy to get support from people at the lower level of the company to participate.
- It was also difficult to collect process data during the various phases of the implementation of the Six Sigma project.

Despite all these challenges, the team has achieved the expected results through the involvement of people at all levels of the organization. As well as many followers for Six Sigma have been developed in the company, with the significant achievement of this initiative.

This project was focusing on the most critical products manufacturing in GEDAC Company which are medium voltage equipment's. As the company offers physical products as well as pre-sales and after sales services. It is suggested for the company to extend the exploration of Six Sigma in their offered services. This is to improve customer satisfaction by improving dependability and speed objectives

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CONFLICT OF INTERESTS

The author confirms that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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