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UNRAVELING KEY DRIVERS FOR ENGINEER CREATIVITY AND MEANINGFULNESS OF WORK: BAYESIAN NETWORK APPROACH

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Abstract

This study builds on an existing structural model developed to examine the influence of leadership and organizational culture on innovation and satisfaction of engineers in Australian public sectors (APS). The objective of this study is to increase the understanding of innovation process with a focus on causal relationships among critical factors. To achieve this objective, the study develops an assessment approach to help predict creativity and work meaningfulness of engineers in the APS. Three quantitative analysis methods were sequentially conducted in this study including correlation analysis, path analysis, and Bayesian networks. A correlation analysis was conducted to pinpoint the strong association between key factors studied. Subsequently, path analysis was employed to identify critical pathways which were accordingly used as a structure to develop Bayesian networks. The findings of the study revealed practical strategies for promoting (1) transformational leadership and (2) innovative culture in public sector organizations since these two factors were found to be key drivers for individual creativity and work meaningfulness of their engineers. This integrated approach may be used as a decision support tool for managing the innovation process for engineers in the public sectors.

Keywords

Creativity, work meaningfulness, path analysis, Bayesian networks, engineers.

Introduction

Engineering is a discipline which requires the experience of innovation. Innovations, of which engineers are key drivers, significantly contribute to an economic system for improving technological progress for both industry and society [1]. One of the major roles of engineers is to transform the abstract into the concrete to meet newly emerging demands [2]. It is also the responsibility of engineers to generate creative ideas because engineering and technology are vital components of most innovations in modern society. In the process of satisfying customer requirements, scientific knowledge can be adapted by engineers to develop new technologies and materials [3]. Solving complex problems in today's fast changing situations and responding to challenges are important duties of an engineer. Therefore, engineers can be seen as a mixture of builders, explorers, and problem-solvers and their goals are to manufacture technical products and provide innovative services to society [4]. For their organizations and industries, engineers are professional staff who generate and adopt innovations which are a function of R&D intensity.

Through their education and professional experience, engineers have the systematic thinking and ability to integrate technology, computations, materials, and designs. Engineers worldwide drive technological innovation and new venture creation through positive feedbacks of R&D efforts [5, 6]. Creativity requires both originality, usually described as novelty, and effectiveness, which take the form of value [7]. Creative engineers often utilize the ability of problem solving to deal with challenges through an intuitive process, while breaking boundaries, identifying patterns, making new connections, and taking chances to make a major breakthrough [8]. Thus, creative engineers are one of the most important elements of an organization's capability to innovate.

From public viewpoint, it seems that engineering creativity is quite limited since most engineers' jobs do not commence in a vacuum, but incrementally develop on existing knowledge and technology [5]. Another indication that engineers may not be perceived as creative is the notion that engineers have become complacent with the status quo and are hesitant to be innovative [9]. Consequently, engineering jobs are not often major breakthroughs, which would characterize the engineer as an innovator. Furthermore, these tasks are usually accomplished by teams and departments, and therefore must attribute success to a group not an individual [10]. However, despite this perception of limited creativity, much of engineering work is inherently creative since it requires the synthesis and application of a variety of concepts to generate an outcome that is substantially different from status quo [11].

The authors recently developed a structural equation modeling (SEM) that explores the relationships through which socio-psychological factors impact workplace innovation and career satisfaction on the innovation process for engineers in the Australian Public Service (APS) [12]. To gain more insights of causal relationships on the developed structural model, this paper extended in more in-depth models to identify the most critical socio-psychological factors and examined how these factors constitute the related organizational outcomes. Specifically, this study conducts an integrated approach that combines path analysis and Bayesian networks (BN) to predict individual creativity and meaningful work of engineers in the APS. The paper begins with an explanation of engineering creativity and work meaningfulness, followed by the proposed research method. A series of quantitative analysis results is then presented. The paper then discusses the key conclusion and ends with future research.

Engineering creativity and work meaningfulness

Engineering creativity as explained by Drabkin [13] is the ability of human intelligence to generate ideas and solutions in engineering domain. Lumsdaine et al. [14] highlight another important issue that interaction with other ideas can help engineers play a key role in facilitating creative outcomes and meaningful connections in the workplace. While in general there are typical components of creativity, many scholars [e.g. 15–17] contend that engineering creativity is different from creativity in other disciplines because engineering creativity always has an objective. With this contention in mind, Cropley and Cropley [16] consider engineering creativity from the perspective of engineering outcomes that conduct the task or solve problems, inclusive of products, devices, or systems. A four-dimensional model was proposed for determining the creativity of engineering outputs according to the following aspects: relevance and effectiveness, novelty, elegance, and generalizability.

Lips-Wiersma and Wright [18] have proposed a definition that expresses the contemporary components of work meaningfulness, asserting that it refers to "an individual subjective experience of existential significance or purpose of work" (p. 657). Meaningful work has a tendency to occur when employees have a clear understanding of their abilities, expected outcomes, and successful operations within their work environment [19]. Moreover, employees are more likely to experience meaningfulness when they know their work effort relates to organizational goals and priorities and contributes to some greater social benefit. Thus, meaningful work occurs when people can apply themselves to significant work activities that serve a valued, broader purpose [20]. Meaningful work is evidently associated with the innovation performance. In a survey of employees from various organizations in Hong Kong, Kim et al. [21] found that employee creativity was positively and significantly associated with employees' work meaningfulness, being part of career satisfaction. Experience meaningful work is important for engineers to fulfill the achievement of their careers.

Methodology

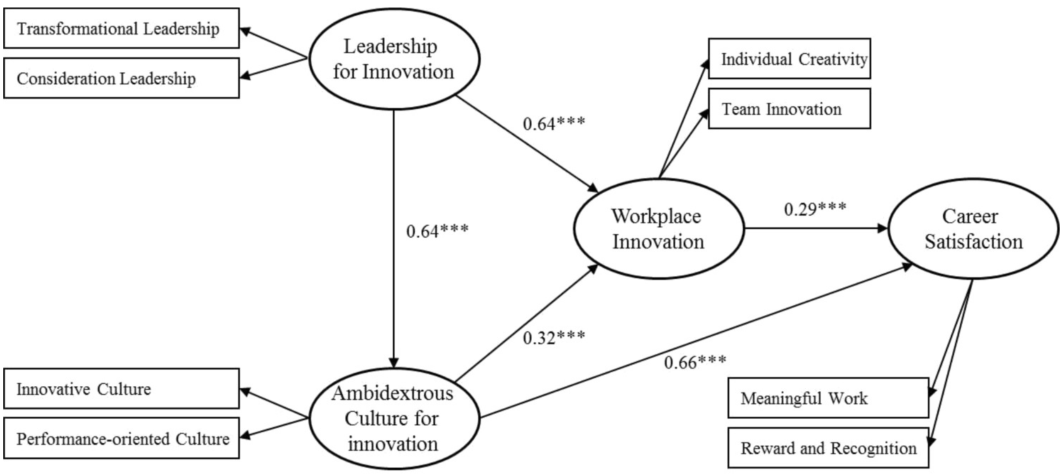
The sample used in this study was drawn from *the State of the Service Employee Census 2014* and further reduced to include only of 3,125 engineers. Secondary data sets have been previously used by researchers interested in investigating innovation in public sectors. For instance, based on data from *the*

2006 Federal Human Capital Survey, Fernandez and Pitts [22] explored how different empowerment practices were used to encourage the innovative behavior of US federal government officers. Using the same data sets, Fernandez and Moldogaziev [23] identified factors that motivated front line bureaucrats in the U.S. federal government to engage in innovative behavior. From an Australian public sector perspective, Demircioglu and Audretsch [24] employed a sample of federal employees from *the State of the Service Employee Census 2011* to explore condition associated with complex innovations and examined how it affected innovation outcomes. Torugsa and Arundel [25] also used *the State of the Service Employee Census 2012* to investigate the effects of empowerment practices on perceived barriers to innovation and determine the most effective method to reduce perceived barriers to innovation. Thus, secondary data sets have been identified by researchers to be valuable sources of information to examine innovation in public sectors.

The reliability and validity of *the State of the Service Employee Census 2014* was tested by Wipulanusat et al. [12]. The authors used factor analysis in structural equation modelling which tested hypotheses related to leadership, organizational culture, innovation, and career satisfaction. The goodness-of-fit values for the conventional indices were acceptable. Factor loadings on latent variables were also all sufficiently high. Combining the goodness-of-fit measures with the factor loadings suggested accurate model specification. Thus, the analysis of *the State of the Service Employee Census 2014* has indicated that this instrument is reliable and valid. The large sample size surveyed in the State of the Service Employee Census, and its widespread coverage of federal departments, can be applied for the generalizability of federal bureaucracy results on a national scale, including the perspective of engineering professions because it reaches the desired population of engineers within the federal government. Moreover, *the State of the Service Employee Census 2014* had many questions that asked about creativity and work meaningfulness. Therefore, *the State of the Service Employee Census 2014* was adopted to conduct the quantitative analysis in this study.

Wipulanusat et al. [12] studied the impact of climate for innovation constructs, namely leadership and organizational culture, on workplace innovation and career satisfaction through the lens of individual engineering professionals in the APS. To better understand innovation process in public sector, the empirical model was conducted using SEM to empirically examine relationships between constructs. The study emphasized the investigation of individual-level and organizational-level factors; therefore, the effects from external environmental factors were not taken into account in the modeling. Furthermore, the study particularly focused on socio-psychological factors which stimulate creativity and innovation in the workplace. Thus, the impediment factors of innovation were not involved in the modeling.

The structural model was presented in Fig. 1. The details of model development and assessment were explained in Wipulanusat et al. [12]. The definitions of 8 factors were summarized in Table 1. The structural model confirmed the causal relationships between the four constructs of the structural model.



Model fit indices: $\chi^2 = 300.89$, $df = 15$, GFI = 0.98, AGFI = 0.95, RMSEA = 0.08, RMR = 0.02, IFI = 0.98, NFI = 0.97, CFI = 0.98, TLI = 0.95
Note: ***$p < 0.001$; For clarity, error terms and variances are not shown.

Fig. 1. Structural model for innovation process [12].

Table 1
Description of factors in structural model.

Model factor	Description
Transformational leadership	Leader who inspires followers to perform, values organizational goals and encourages subordinates to work beyond standard level [26, 27].
Consideration leadership	Leader who provides support for followers, arranges welfare, builds workplace equality, and displays feeling of warmth [26].
Innovative culture	An organization which focus on experimenting with new solutions, valuing flexibility, supporting creativity and entrepreneurship [28, 29].
Performance-oriented culture	Organizational characteristics that focus on goal orientation, task performance, and quality of service delivery [28, 29].
Individual creativity	The individual ability to develop new creative solutions and practices to workplace, providing a practical and useful outcome for an organization [30, 31].
Team innovation	The application within a team of novel ideas, products, processes, or services that are and that can be implemented to address organization's challenge [31, 32].
Meaningful work	A positive meaning that employees recognize in the workplace and an individual's subjective experience of purpose of their job [18, 20].
Reward and recognition	A return on employees' performances in terms of the financial rewards, promotions as well as respect and recognition from peers [33].

Leadership for innovation shows a strong and positive influence on ambidextrous culture for innovation (0.64, $p < 0.001$) and workplace innovation (0.64, $p < 0.001$). Ambidextrous culture for innovation has a moderate and positive impact on workplace innovation (0.32, $p < 0.001$). The workplace innovation was found to be a moderate and positive influence on career satisfaction (0.29, $p < 0.001$). Finally, a significant path has been found from ambidextrous culture for innovation to career satisfaction, presented by the strong and positive standardized coefficient (0.66, $p < 0.001$). Gaining this understanding of these relationships means the structural model can be adopted to help solve the current problem of shortage of engineers in Commonwealth departments. The findings of the relationships between the constructs reveal the significance of giving engineers with sufficient chances to participate in innovative activities to improve their career satisfaction.

However, the structural model illustrated only the relationships between constructs which factors acted as indicators for latent constructs. Specifically, the structural model explains on relationships between construct, providing no detail of interrelationships between each factor (i.e. indicator). To increase the analytical capacity of structural model, the relationship of each factor need to be examined in more detail which can reveals critical pathway of factors within the empirical model.

The structural model was adopted as research model for this present study. There are three quantitative analysis methods sequentially conducting in this study which are: (1) correlation analysis; (2) path analysis; and (3) Bayesian networks. Correlation analysis was conducted to reveal relationships between factors within model constructs which can determine the strong association of these factors. Path analysis was used to investigate the potential causal relationship of the critical factors. The BN was developed to enhance the explanatory power of the path analysis by analyzing the variables at the factor level in order to examine cause-and-effect relationships [34].

Data mining refers to the process of discovering unknown, implied, effective and practical information from mass data. Data mining technique consists of classification, clustering, optimized set reduction, and Bayesian networks [35]. Compared with other data mining techniques, the BN has a unique capability that integrates an intuitive visual representation of the causal map between cause and effect, which is developed based a sound mathematical basis of probability theory. As a result, the BN fulfils data mining task including forecast, classification and clustering of optimization method. Baraldi et al. [36] compares the ability of the BN and Fuzzy Logic (FL) for managing the uncertainty of the input assessment. While both approaches are very useful for the treatment of uncertainty related to the dependence modeling and assessment, they have different abilities to manage the uncertainties of the input assessment, propagating to the outcome. The in-depth comparison reveals that the BN is the preferred method over the FL for all the cases where probability distributions can be used to quantify the uncertainty of input parameters. This is because it meets the requirement of the uncertainty representation and its output can be directly interpreted for the analysis. Therefore, BN is the appropriate probabilistic framework for the treatment of uncertainty from a mathematical perspective and practitioner viewpoint.

Results

Correlation analysis

The structural model has been tested to confirm the relationships between model constructs. This study adopted Pearson correlation analysis to determine strength of association between factors within model constructs. Because positive relationships were confirmed in structural model, one-tailed tests were conducted to provide confident results and identify the strong correlations between factors. This study adopted Cohen's effect size classification for correlation coefficients to determine the strength of relationships between the factors. The size classifications are identified as: small (0.10–0.29); medium (0.30–0.49); and large (≥0.50) [37]. The factors that had large effect sizes of relationships (i.e. the correlation coefficients greater than or close to 0.50) were determined as 'critical'. Therefore, these critical factors were selected to use in the following path analysis.

Table 2 shows the correlation matrix presenting the correlations between the independent and dependent factors corresponding with the constructs in structural model (see Fig. 1). This correlation matrix was to determine statistically significant correlations ($p < 0.05$). Overall, six factors associated with large effects were identified from the correlation coefficients greater than or close to 0.50, as highlighted in the table. These critical factors include:

- two factors from the LFI construct, namely, transformational leadership (LFI1) and consideration leadership (LFI2);
- one factors from the ACI construct being innovative culture (ACI1);
- one factors from the WIT construct being individual creativity (WIT1); and
- two factors from the CSF construct being meaningful work (CSF1) and reward and recognition (CSF2).

Path analysis

After identifying critical factors from correlation analysis, path analysis was used to assess the causal relationships among critical factors. In particular, path analysis is a powerful approach to present complicated relationships and related estimated parameters in a graphical language [38]. Path analysis is commonly called simultaneous equation modelling when all variables in a path model are observed. The model consists of exogenous and endogenous variables. Exogenous variable is an independent variable which no arrow points to this factor, whereas endogenous variable refers to as a dependent variable which is predicted by other variables in the path model [39]. The equation of path model can be expressed as follows:

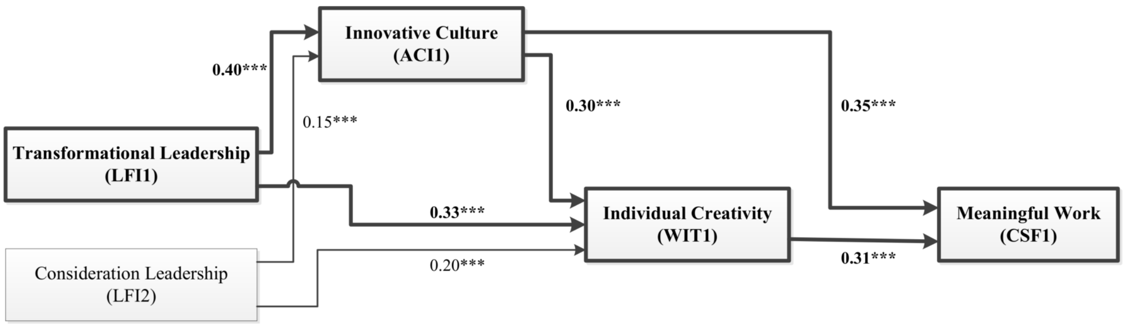
$$y = By + \Gamma x + \zeta, \tag{1}$$

where y is the vector of the endogenous variables; B is the matrix containing the coefficients denoting directed paths between the endogenous variables; Γ is the matrix containing the coefficients for the equations specifying paths from the exogenous variables to the endogenous variables; x is the vector of the exogenous variables; ζ is the vector of the residuals from the structural relationships between y and x.

Table 2
Correlations between model factors.

	Independent factors							
Dependent factors	<u>LFI1</u>	<u>LFI2</u>	<u>ACI1</u>	ACI2	<u>WIT1</u>	WIT2	<u>CSF1</u>	CSF2
LFI1	1							
LFI2	0.68**	1						
ACI1	**0.51****	0.43**	1					
ACI2	0.37**	0.34**	0.56**	1				
WIT1	**0.62****	**0.56****	**0.56****	0.32**	1			
WIT2	0.46**	0.40**	0.44**	0.39**	0.55**	1		
CSF1	0.46**	0.41**	**0.53****	0.36**	**0.51****	0.40**	1	
<u>CSF2</u>	0.49**	0.44**	**0.69****	0.44**	**0.51****	0.38**	0.59**	1

Correlation coefficients greater than or close to 0.50 are **bold** and their corresponding factors **underlined**; **$p < 0.05$ (one-tailed).



Model fit indices: $\chi 2$ = 77.96, *df* = 2, GFI = 0.99, CFI = 0.99, TLI = 0.94, IFI = 0.98, SRMR = 0.02, RMSEA = 0.08
Note: ****p* < 0.001; For clarity, error variances are not shown.

Fig. 2. Path model.

Path analysis was conducted using SEM technique to examine the causal relationships of the six critical factors as illustrated in the empirical model. Root mean squared error of approximation (RMSEA) is the absolute fit index, used for model selection to estimate the lack of fit to the saturated model, representing the under-fitted between the proposed model and the population [38]. The RMSEA can be referred to the following formula:

$$\mathrm{RMSEA} = \sqrt{(X_S^2/df_S) - 1/N}, \qquad (2)$$

where, the chi-square is presented as X_S^2, the degree of freedom is denoted as df_S; the sample size is represented by N.

According to Hair et al. [38], the RMSEA value which equals to zero can be interpreted as perfect fit; the threshold of RMSEA less than or equal to 0.08 is used as an acceptable level of the model. For the path model to be considered as having an acceptable fit, all six indices were measured against the following criteria: GFI, CFI, TLI, and IFI > 0.90; SRMR < 0.05; and RMSEA < 0.08 [38, 40].

To analyze the data using SEM, the Analysis of Moment Structures (AMOS) version 22 was employed to allow the data from the SPSS analysis set to be directly used in the AMOS calculation [40]. Also, AMOS graphics integrate an easy-to-use graphical user interface with a complex computing engine that makes its use attractive and provides estimations of most necessary parameters. From the initial results, the path model did not fit the observed data. Model trimming was conducted to suggest the possible removal of paths or indicators. To do so, modification indices (MI) and expected parameter change (Par Change) were used to reveal areas of model misspecification. Analysis of the MI and Par Change resulted in the elimination of reward and recognition (CSF2). As shown in Fig. 2, the model trimming yielded the final path model the results of goodness of fit indices demonstrated an acceptable level of model fit ($\chi^2 = 77.96$, $df = 2$, GFI = 0.99, CFI = 0.99, TLI = 0.94, IFI = 0.98, SRMR = 0.02, and RMSEA = 0.08).

Table 3 present the summary of structural equations, standardized coefficent, standard error and critical ratio. From the path model, transformational leadership and consideration leadership were considered as exogenous factors (γ). The remaining variables consisted of innovative culture, individual creativity, and meaningful work were defined as endogenous factors (β). According to the estimated coefficients, five of seven causal relationships had 'meaningful' standardized coefficients, being greater than or close to 0.30 [37]. Thus, these causal relationships were considered as critical paths in the model. Transformational leadership was significantly and positively related to innovative culture ($\gamma = 0.40$, $p < 0.001$)

Table 3
Structural equations of critical paths.

Critical paths	Structural equations	Coefficient	S.E.	C.R.
LFI1 $\to$ ACI1	$Z_{ACI1} = 0.40(Z_{LFI1})$	$\gamma = 0.40$	0.02	19.32***
LFI1 $\to$ WIT1	$Z_{WIT1} = 0.33(Z_{LFI1}) + 0.30(Z_{ACI1}) + 0.20(Z_{LFI2})$	$\gamma = 0.33$	0.02	17.60***
ACI1 $\to$ WIT1		$\beta = 0.30$	0.01	20.21***
ACI1 $\to$ CSF1	$Z_{CSF1} = 0.35(Z_{ACI1}) + 0.31(Z_{WIT1})$	$\beta = 0.35$	0.02	20.03***
WIT1 $\to$ CSF1		$\beta = 0.31$	0.02	18.00***

Note: ***$p < 0.001$; S.E., Standard Error; C.R., Critical Ratio and individual creativity ($\gamma = 0.33$, $p < 0.001$). Innovative culture was also significantly and positively related to individual creativity ($\beta = 0.30$, $p < 0.001$) and meaningful work ($\beta = 0.35$, $p < 0.001$). There was a significant and positive relationship between individual creativity and meaningful work ($\beta = 0.31$, $p < 0.001$). The path model was used as a structure to develop Bayesian networks in the following section.

Bayesian network

Bayesian networks (BN) develop a causal map between cause and effect based on probability theory relies on the mathematical model of the Bayes' theory [41]. A Bayesian network is defined as directed acyclic graph (DAG) where the nodes present the cause of an event by parent node (Y) and the outcome by a child node (X), which the Bayes' rule can be defined as the following formular:

$$P(Y|X) = \frac{P(X|Y \cdot P(Y)}{P(X)}, \tag{3}$$

where $P(Y|X)$ is the probability of Y given X, presented as the posterior probability; $P(X|Y)$ is the conditional probability of X given $Y, P(X)$ is the prior probability of X; $P(Y)$ is the prior probability of Y.

Suppose that the BN is represented by ordered pairs N(G, p), the BN can be presented as follows:

- The graph $G = (V, E)$ is DAG and p is the joint probability over the variables V.
- A set of V (e.g., $V = \{X_1, X_2, ..., X_n\}$) is presented as nodes. A set of directed edges is presented as E.
- Variable π_i represents the set of parents' nodes with a direct link to X_i .

Thus, the joint product of these conditional probabilities constitutes the joint probability of the network, referring to the following formula given below:

$$P\left(X_1, X_2, ..., X_n\right) = \prod_{i=1}^{N} P\left(X_i \left|\pi_i\right.\right). \tag{4}$$

The arrows represent the causal relation between the linked nodes, and the strengths of these dependencies are quantified by conditional probability tables (CPT). The total number of the CPT can be calculated by the following equation:

$$\sum_{i=1}^{V} \left[S \prod_{j=1}^{n} P_j \right], \tag{5}$$

where S is the number of states of the child node, P_j is the number of states of the j-th parent node, for n parent nodes, among a set of V nodes in the model.

The BN was developed from an empirically derived path model to predict individual creativity and meaningful work. Netica was the software used for parameter learning to construct the BN. As present in Fig. 3, the BN consists of 5 nodes and 7 causal relationships between nodes. All nodes were divided into three states according to the chance of occurrence: [1–2.5] as low, [2.5–4] as medium, and [4–5] as high. Each state has the probability distribution value based on the conditional probabilities calculated from the DAG and corresponding data.

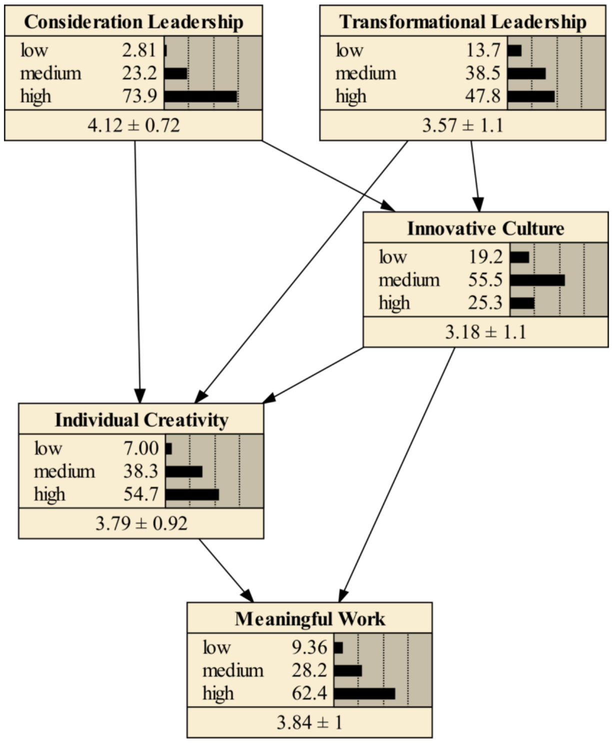


Fig. 3. The original scenario.

The critical paths were used to develop the optimistic scenario for individual creativity and meaningful work, as illustrated in Fig. 4. In order to assess the important of the critical path, the chances of 100 percent occurrence of a high state were entered to both transformational leadership and innovative culture. This resulted in the odds of high individual creativity reaching 82.8 percent whereby the mean value increased to 4.25, thus meaning an increase of 12.1 percent (3.79 → 4.25). Subsequently, the chance of high meaningful work increased from 62.4 to 87.7 percent, reflected an increase in the mean value by 12.2 percent (3.84 → 4.31).

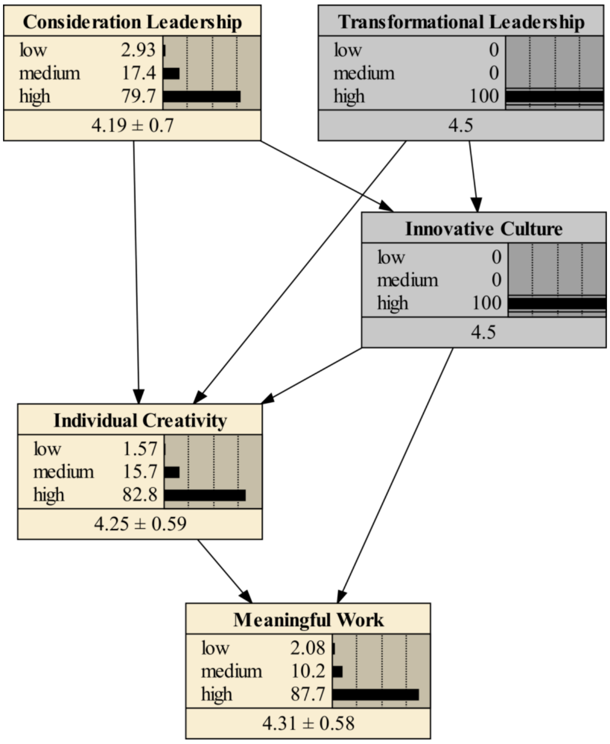


Fig. 4. The optimistic scenario.

The maximum improvement of creativity and work meaningfulness of engineers can be achieved through evidence of high transformational leadership and high innovative culture, as presented in the optimistic scenario. Therefore, if federal departments desire to increase creativity and work meaningfulness of their engineers, then leaders should adopt transformational leadership style and instill innovative culture in their organizations. Transformational leadership style can be successfully developed through a practice which combines of feedback, structured workshops, mentoring, and coaching. 360 degree. Feedback is practical tool to identify weaknesses in leader behavior, and can improve leader self-awareness [42]. Transformational leadership also plays an important role in encouraging and sustaining an innovative culture in their organization.

Conclusions

The objective of this research is to increase the understanding of innovation process in the public sector context from engineers' perspective. To achieve this objective, this study has proposed an integrated approach that links path analysis used to identify causal relationships between critical factors, subsequently adopted as directed acyclic graph (DAG) for Bayesian networks (BN). Using an empirical model as a research input, this paper identifies critical pathways for increasing individual creativity and ultimately enhancing work meaningfulness of engineers. This integrated approach can be used as a decision support tool to manage the innovation process in public sector organizations. The findings provided practical strategies for public sector organizations to increase individual creativity and ultimately enhance work meaningfulness, as summarized below.

It was found that individual creativity is the critical determinant of meaningful work of engineers in the APS. The organization, therefore, needs to identify attributes that are considered by the engineers influencing their creativity. These attributes were categorized as: desire and fulfilment; autonomy and support; openness and knowledge; and, engrossment and connection [2]. Desire and fulfilment summarize the intrinsic motivation of creative individuals; they tend to be dissatisfied with the mundane problems of engineering and want to be creative in producing novel and different solutions. For instance, according to a study by Amabile and Pillemer [30], when individuals were interested in the problem area, the problem was more likely to be solved via the exploratory route. They also argued that problem solvers enhanced their creative ability if they focused deeply on a task. In summary, creative desire is a trait of engineers who constantly strive for chances to innovate, and consequently, this allows them to express novel solutions. Therefore, engineers who participate in creative projects are aware of an intrinsic motivation in their engineering tasks, and this could ultimately lead to engineers' psychological perception of meaningful work.

Autonomy and support describe the working environment in which creativity is encouraged. More specifically, autonomy relates to the freedom to experiment, which is necessary for an individual to take the risks required to pursue new ideas [2, 43]. The organization that promotes innovative culture places great value on the work autonomy of their engineers [29, 44]. In contrast, constraints consistently hinder creativity and decrease task motivation [30]. When an individual perceives external controls (e.g. rewards, time pressure, surveillance, evaluation, and even the expectation of evaluation) when performing tasks, their intrinsic motivation receives negative influences. A supportive environment is described by Klukken et al. [2] as one where engineers have the freedom to experiment and take the necessary risks to pursue new ideas and where failure is an acceptable outcome. This finding is consistent with a study by Rogers [45] who demonstrated that creative contributions require contexts of psychological safety and freedom, well separated from a blame culture.

Innovative attempts should be recognized for both successful and unsuccessful results. Therefore, leaders should provide supportive and independent environments, as well as time and resources according to the required demands of creative engineers. These are characteristics of transformational leadership which show full support to stimulate engineering creativity in their agencies through leaders' own action [27].

Knowledge is a cognitive tool which engineers must have the ability to be expert in a technical discipline, while maintaining openness to new knowledge and insight and a willingness to learn. Engineering creativity requires solid technical skills and a sound knowledge base. In addition to knowledge, the creative engineer should have a deliberate openness, which means they can also acquire and accept critiques of possible solutions to the problem from other experts. This means they have the ability to connect remote elements and produce creative links. This working environment allows creative engineers to practice lateral thinking, adapt their thought process, and employ one field of knowledge to solve problems in another domain [2, 46]. Thus, a strong background in a specific discipline is necessary, but innovation can only be achieved when engineers are also able to make connections between knowledge domains which are not normally associated.

Teamwork and communication skills also play an important role in this attitude of deliberate openness. Working in a team can significantly improve creative productivity, compared to working alone [16]. Supporting a creative engineer can be achieved by providing access to the necessary knowledge base and allowing sufficient time to gather and absorb that information. This knowledge can be utilised in a suitable way. Engrossment and connection consider the experience of total attention on an issue which includes focus and flow [11]. A sense of total engrossment and connectedness should occur in the creative process in order for a problem to not only connect to the context but also all other available and relevant knowledge domains [47].

Practical implications

Prior to this study, *the State of the Service Series Report 2013–2014* was the first and only time the measures of transformational leadership were tested and reported across the Australian Public Service (APS) [48]. The APS Commission has since discontinued studying transformational leadership in subsequent studies with no stated reasoning. However, this study found evidence for its importance and suggests that the APS could encourage management to consider adopting a transformational leadership style.

It is recommended that the Full Range Leadership (FRL) model should be included in APS management training and development programs. The FRL model suggests that managers do not have to be "perfect" leaders who demonstrate total transformational leadership. The fundamental point is a change in the balance of leader behaviors away from transactional leadership and more towards the transformational leadership style [49]. Originally, transformational leadership was expected to be distinct from, and more effective than, reward or transaction-based leadership, where leaders seldom advised subordinates, and instead concentrated on awarding and penalizing designated actions [50]. However, empirical findings have consistently suggested that because employees have transactional needs, transformational leaders should augment their use of beneficial transformational behaviors by also implementing a transactional leadership style which offers rewards as a path to increase performance [51, 52]. This study also recommends that before implementing innovative projects, federal departments should recruit supervisors who have a transformational leadership style. This recommendation requires the APS to change its recruitment, selection, and promotion processes. Such change could be achieved using the Multifactor Leadership Questionnaire (MLQ) to assess leadership behaviors and provide incentive mechanisms which encourage managers to adopt a transformational leadership style [53].

In terms of organizational culture, the APS currently applies the performance culture model to identify and explain different cultures within an agency. The model proposes that such cultures vary along four dimensions for organizational performance: task, innovation, process, and people [48]. In 2014, the APS performance culture profile, across all agencies, showed that the greatest emphasis was placed on process and task. The innovation dimension showed the lowest score, reflecting employee perceptions that innovative culture was the least emphasized dimension across the APS.

This study has shown that it is essential for the APS to encourage and sustain an innovative culture. To achieve this, the APS can use the Innovation Quotient instrument developed by Rao and Weintraub [54], which consists of six factors: values, resources, behaviors, processes, climate, and success. This instrument can assess how employees perceive the presence of innovative culture. Emphasis should be given to the three critical areas of values, behaviors, and climate particularly, as these are the factors most often neglected and least frequently measured in organizational culture [55]. Leaders can use the Innovation Quotient assessment results to identify the strengths and weaknesses of these factors within their organization. Although most leaders want to immediately fix weaknesses, the best strategy to promote an innovative culture is to focus on strengths, start small, and leverage successes into a broader transformation over time. This can be achieved by transformational leaders who inculcate innovative culture in order to foster individual creativity and fulfil employee perceptions of reward and recognition.

Future research

The state of engineering education always plays an important role in encouraging creative thinking. Engineers should be educated to be on the frontier of exploration and in the vanguard of innovation which requires new abilities and knowledge that equip them with additional hard (i.e. professional) competencies and soft (i.e. social) competencies that enable them to work across disciplines, to manage risk and uncertainty, to integrate and coordinate, and, ultimately, to innovate. In fact, improving products, processes, and systems in modern societies increasingly relies on engineering creativity, entrepreneurship, and innovation, meaning that values such as originality, ingenuity, and novelty are critical elements of engineering competencies [47]. Clearly, a *high level* and *lifelong internal* motivation is an important trait of creative engineers. However, current educational systems have often been found to be counterproductive to that motivation. Moreover, the detailed competencies of engineers that engender creativity and innovation are not represented within tertiary curricula, or publicly depicted as having relevance to societal requirements [9]. This means engineering schools often do not provide students with sufficient understanding of creative contributions and preparation for competencies required in modern industry. Accordingly, future work could be conducted by using such technique as Grey Clustering Analysis to develop the engineers' competency model that engineering schools can help equip students with necessary competencies demanded by our society with increasing technology-driven innovation [56].

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