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Employee Commitment to Innovation Performance: Investigating the role of Knowledge Acquisition and Knowledge Sharing

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Abstract

Organisational commitment is suggested as a remarkable variable in shaping employees' attitudes toward knowledge management practices. Customer trust in services is established during a long-time relationship with a firm and improves the accuracy of information shared with employees. To put it in other words, customer trust is what a service company needs to maintain its competitive advantage. On the other hand, high employee turnover reflects a substantial loss of knowledge. In the present study, the impact of organisational commitment on employees' retention, knowledge acquisition, and sharing was examined regarding the moderating roles of leader-member exchange and innovation climate. The research sample encompassed 250 employees of the leader of Iran hotel industry. Data extracted from the questionnaires were analysed using the partial least squares structural equation modelling method. The findings revealed that organisational commitment had a positive impact on employees' retention and knowledge acquisition and sharing, and that leader-member exchange and innovation climate reinforced the connections. Managers may use the research findings for the effective implementation of the knowledge management practices.

Keywords: Knowledge Sharing, Knowledge Acquisition, Commitment, Innovation Climate, Leader-Member Exchange

1. Introduction

Knowledge is valuable leverage for organisations to maintain sustainable progress while facing fast transmission in the business environment (Rehman et al., 2020). Due to the changing environment and customer demands, service organisations now exercise the practice of urging their employees to innovate (Alosani et al., 2020). From the perspective of dynamic capabilities, firms should acquire and combine knowledge within and outside the organisation to detect and exploit potential opportunities to innovate to survive (Teece, 2017). Knowledge management (KM) combines knowledge acquisition, development, sharing, and application (Razzaq et al., 2019). Thriving innovation performance demands knowledge to be explored and exploited within a firm, and employees to be central to knowledge acquisition and diffusion practices (Curado et al., 2017). The more employees are involved in knowledge sharing, the more incredible deal of knowledge would be internalised in employees; such conditions benefit innovative behaviour (Ullah et al., 2021). Employee commitment was a critical factor in the these individuals' involvement in the KM practices (Rehman et al., 2020). Besides, employee retention fosters knowledge acquisition and, consequently, innovation performance (Papa et al., 2018).

Meanwhile, employee commitment is reported to significantly influence employee retention intention (Pertiwi & Supartha, 2021). Employees will be more willing to develop an amicably interpersonal affiliation with their superiors, less likely to leave a specific organisation (Yildiz, 2018). Moreover, an organisational climate that inspires innovation would affect employees' intention to engage in KM-related behaviours. A propitious climate for innovation is characterised as a climate that promotes pro-social norms, persists on free influx and circulation of information, and permits justifiable failure (Jokanovic et al., 2020).

Given the critical role of the hotel sector in national and global economies (Bazazo & Alananzeh, 2020), besides the under-explored role of customer commitment and retention influence on knowledge sharing and acquisition in the hotel industry in Iran, and call for more investigations in the relation between human resources (HR) on innovation and KM (Mahmoud et al., 2021; Rasdi & Tangaraja, 2020; Shahzadi & Raja, 2021), and innovation climate potential outcome at the organisational level (Newman et al., 2020), the present study aimed to address the following research questions to fill in the research gap:

RQ1; How does employee commitment to the organisation affect knowledge acquisition, knowledge sharing, employee retention, and the nexus between knowledge acquisition and sharing and the connection between employee retention and knowledge sharing?

RQ2; Does leader-member exchange (LMX) moderate the employee commitment link to employee retention?

RQ3; How does the innovation climate influence employees' commitment concerning knowledge acquisition sharing?

The survey was conducted in the Iranian hotel sector context in Parsian Hotel Group. Present study findings would shed light on employee participation behaviour in KM practices.

The paper is outlined as follows: In Section 1, theoretical background, hypotheses, and conceptual research model are provided. Section 2 contains research methodology and sampling data. The hypothesis test is presented in Section 3. Theoretical and managerial implications and conclusions are presented in Section 4, and the guidelines for future researches are delineated in Section 5.

2. Research Background

2.1 Organisational commitment

Oganisational commitment is theorised in various approaches since the 1960s. Porter et al. (1974) define it as the degree of an employee's identification with and engagement in a particular firm. Jonsson and Jeppesen (2013) suggested commitment as members' organisational interest and sense of belongingness to the organisation. In another approach, organisation commitment is characterised under three subsections known as an affective, continuance, and normative commitment by Meyer and Allen (1987), adopted in the present research.

2.2 Organisational Affective Commitment

Buchanan (1974) defines affective commitment as employee commitment to the "values and goals" of a particular firm in relation to employee own values and goals and commitment to the firm for its own sake, apart from by associated fiscal value. Another approach is specified it as the employee's "emotional attachment, identification, and involvement" with the particular firm and its goals (Porter et al., 1979). Robbins (2007) described affective commitment as the extent that an employee identifies with a firm and the degree of intentions to continue his/her participation in the affiliated organisation.

2.3 Organisational Normative Commitment

Wiener (1982) describes normative commitment as an "internalised normative pressure" oriented toward firm "goals and interests" and argues that employee normative commitment is merely through believing as a "right" and moral action. Meyer and Allen (1991) supported this type of approach with their definition of "a feeling of obligation." Prestholdt et al. (1987) identified normative commitment as an essential employee driver not to terminate membership with a particular firm. Robbins (2007) explained normative commitment as an individual commitment to stay in the organisation for ethical or moral causes.

2.4 Organisational Continuance Commitment

Continuance commitment inhibits an individual from altering his/her social identity due to the recognition of massive forfeits associated with alternation (Stebbins, 1970). Becker (1960) stated continuance commitment as an employee intention to "engage in consistent lines of activity" based on the individual's perception of the "costs" corollary of ending employment. When an employee faces losses for quitting the organisation in the form of penalties and costs, continuance commitment is formed (Allen & Meyer, 1990). Continuance commitment results in a trade-off between the fiscal value of keeping membership in a particular firm and terminating the employment (Robbins, 2007).

2.5 Employee Retention

Employee retention is defined as "the propensity of employees to withdraw from a particular job"(Jung et al., 2017) or the "probability of employees leaving their organisation" (Wynen et al., 2017). A committed employee is found to own higher proclivity to retain in a particular organisation, and retention intention kindle the employee to enrich their knowledge in the specific scope (Politis, 2003). Accordingly, provided that an employee possesses a strong sense of commitment and retention, he/she would exhibit a higher tendency to infer the necessity to acquire and integrate knowledge (Weber & Tarba, 2010).

2.6 Knowledge Acquisition

Knowledge acquisition is the process of information and knowledge collecting (Huber, 1991) and demands searching and merging information and knowledge from inside and outside of the organisation (Scuotto et al., 2017). Employees are required to contrive new solutions to devise noble products/services tailored to customers' needs (Al-Jobor et al., 2020; Vrontis et al., 2017), and acquire competitive advantages. Pertinent knowledge should be elicited either inbound or outbound of a firm and employed as well (Campanella et al., 2017).

2.7 Knowledge sharing

Tendency to share the knowledge is quintessential to implement KM (Edwards, 2017) and is vital in group and organisation contexts to acquire a competitive and supreme outcome (Evwierhurhoma & Onouha, 2020). Knowledge sharing is continuous knowledge exchanging via established networks among individuals, groups setting, and organisations levels (Igwe & Ononye, 2020; Sedighi et al., 2018). Furthermore, knowledge sharing behaviour facilitates access to the information and knowledge required by organisation members for job performance (Swanson et al., 2020), and the utilisation of knowledge-based resources (Oyemomi et al., 2016) consequently enhances efficiency and lead to organisational innovation (Ullah et al., 2021).

2.8 Organisational Innovation Climate

Organisational climate is defined as shared values, beliefs, and organization atmospheres that significantly impact employees' behaviours (Martin-de Castro et al., 2013). The innovation climate provides a cultural context to enable knowledge sharing, induce creativity, and breed innovative ideas (Popa et al., 2017). The innovative climate of organisations is the degrees of innovative culture, job autonomy, organisational learning, and group cohesion in an organisational context (Balkar, 2015). Ren & Zhang (2015) describe organisation innovation climate as a support for developing innovations, including leadership for promoting innovation, infrastructure for appraising ideas, and adequate financial support for promoting innovation. A perceived work climate for innovation incites an employee's innovative behaviour (Park & Jo, 2018). Provided by an innovative climate, when a team is confronted with a particular project dilemma, the members may participate in their work teams aggressively and communicate with each other openly to find out appropriate solutions (Liu et al., 2012). On this ground, the presence of an innovation climate is conducive to higher organisational performance (Shanker et al., 2017).

2.9 Leader-member exchange (LMX)

LMX is an extension of employee perception of being supported by his/her associated supervisor (Tubay, 2019). LMX theory shows how the leaders connected with employees impacting employees' attitudes and performance in the ascribed jobs (Graen & Uhl-Bien, 1995). Bhal and Ansari (1996) introduced two dimensions of LMX, "perceived contribution and affection." Dienesch and Liden (1986) consider LMX a three-dimensional factor, perceived contribution, loyalty, and affection. The four-dimensional LMX model; however, included "incorporating contribution (perception of the current level of work-oriented activity each number puts forth toward the mutual goals of the LMX dyad (loyalty) the expression of public support for the goals and personal character of the number of the dyad), affect (the mutual affection leader-member dyad have for each other based preliminary on the interpersonal reaction), and professional respect (perception of the degree to which each member of the dyad has built a reputation within and /or outside the organisation)" (Liden & Maslyn, 1998). The four-dimensional LMX model is adopted in the present research.

LMX can be perceived within the high to low spectrum. The highest level of LMX can be attributed to trust, mutual respect, reciprocal obligations between leader and member (Loi et al., 2014), and employees' more precise understanding of organisation value (Kasekende et al., 2016). Under such desirable ambiance, employees may experience higher motivation and satisfaction than those who perceived a lower level of support from pertinent managers (DeConinck, 2011; Rockstuhl et al., 2012). Owing to more outstanding interpersonal and psychological support, organisational resources granting, and higher autonomy awarding to the employee by the leaders in a high-quality LMX context, generating innovative ideas would be highly likely (Parzefall et al., 2008).

3. Hypotheses and conceptual research model

Organisational commitment predicts the various scope of work such as organisational citizenship behaviour (Sheikh & Aghaz, 2019), quality of performing the ascribed job (Atmojo, 2015), higher level of engagement (Albdour & Altarawneh, 2014), and the quality of provided service (Dhar, 2015a). Individuals with higher emotional attachment prioritize the organisational objective over their interests and desires. Moreover, they are predisposed to take part in KM practices (Ahmed et al., 2018; Gopinath, 2019) and inclined to share their knowledge with their colleagues (Curado & Vieira, 2019; Imamoglu et al., 2019; Naeem et al., 2019; Rasdi & Tangaraja, 2020; Rehman et al., 2020).

Accordingly, the following hypothesis was proposed:

H1. Organisational commitment positively affects knowledge sharing.

Whether information and knowledge are acquired from the inside sources, through organisation instructions on processes or information transferred to them from counterparts, or outside sources such as competitor or market data, in knowledge acquisition behaviour, employees' capabilities and motivation play a vital role (Senge, 2006). However, knowledge acquisition is accompanied with tension in the organisation, which should be inspired through human resource management (HRM) practices (Chesbrough et al., 2014) in processes and activities increasing job security, commitment, and risk-taking behaviour (Wright & Nishii, 2007). Previous studies reported a positive link between knowledge acquisition strategies and employee commitment (Bogers et al., 2018; Khoa & Hoa, 2021).

Accordingly, the following hypothesis was proposed:

H2. Organisational commitment positively affects knowledge acquisition.

Knowledge acquisition demands well-established information technology, along with auspicious culture and leadership support that motivate information sharing (Aujirapongpan et al., 2010). Meanwhile, studies suggested knowledge acquisition positively affects attitude towards knowledge sharing (Oye et al., 2011; Chang & Shih, 2010).

Accordingly, the following hypothesis was suggested:

H3. Knowledge acquisition positively affects knowledge sharing.

Promoting innovation climates is employee's satisfaction, engagement, and commitment tailwind (Kim & Fernandez, 2017). Organisational commitment, enabled by a positive social climate that stimulates creativity, information adoption, knowledge sharing, and innovation, acts as stimuli for employees to fulfil the firm goals (Jokanovi et al., 2018; Popa et al., 2017; Soto-Acosta et al., 2017; Zywiolek et al., 2021). Innovation climate is a critical factor in establishing a favourable attitude toward KM and succeeding action of embracing KM practices (Ullah et al., 2016), knowledge sharing (Edu-Valsania et al., 2016), and innovative behaviour (Dhar, 2015b). These factors can be achieved by prompting employee's desire for innovation, authorising risk-taking behaviour, and promoting his/her confidence and safety (Kang et al., 2016).

Accordingly, the following hypotheses were proposed:

H1-1. Innovation climate as moderator positively affects organisational commitment and knowledge sharing.

H2-1. Innovation climate as a moderator positively affects organisational commitment and knowledge acquisition.

High turnover in the hotel industry is a long-standing discussion. Turnover costs could be narrowed to decline of knowledge and experience massively, risk the customer satisfaction, and jeopardise the brand loyalty and image (Dusek et al., 2014). The key to shrinking employee turnover is boosting employee commitment (Arini, 2019) as highly committed employees tend to show high-quality performances and low turnover rates (Akbar et al., 2017). According to some studies, organisational commitment significantly engenders employee retention (Dewi & Riana, 2019; Naz et al., 2020; Putra et al., 2020).

Accordingly, the following hypothesis was proposed:

H4. Organisational commitment positively affects employee retention intention.

Employee retention is widely believed to be beneficial to an organisation's knowledge transfer outcome. Employee turnover will be negatively associated with knowledge transfer (Martin-Perez & Martin-Cruz, 2015) and absorptive capacity (Larkin & Burgess, 2013).

Accordingly, the following hypothesis was proposed:

H5. Employee retention intention positively affects knowledge sharing.

The concepts of LMX antecedent on employee turnover intentions is an ongoing and prominent issue in HRM (Yildiz, 2018). The higher the employees' perception of the support from leaders, the higher the employees' loyalty to the firm (Kim & Yi, 2019). LMX has a psychological impact on the employee, evinced in employee developing organisational identification, compassion, satisfaction, job embeddedness, and retention intention (Dechawatanapaisal, 2018; Park & Lee, 2020).

Accordingly, the following hypothesis was proposed:

H5-1. LMX as a moderator positively affects organisational commitment and employee retention intention.

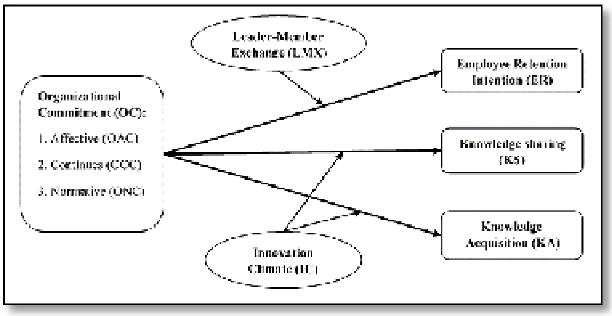


Figure 1. Study Proposed Model

4. Research Methodology:

The study population is 400 employees of Parsian Hotel Group, and according to Cochran's sample size formula, the sample size was calculated (Equation 1) (Cochran, 1977). Minimum approvable sample size with z=1.96, p=q=0.5, and d= 0.05 and N=400 was estimated to be 200 persons.

$$n = \frac{\frac{z^2pq}{d^2}}{1+\frac{1}{N}\left[\frac{z^2pq}{d^2}-1\right]} = \frac{\frac{1.96^2\times 0.5\times 0.5}{0.05^2}}{1+\frac{1}{400}\left[\frac{1.96^2\times 0.5\times 0.5}{0.05^2}\right.} \quad (1)$$

Therefore, a sample of 250 employees was randomly selected. The fieldwork and questionnaire tools were applied for data collection to test the research hypotheses. A partial least squares structural equation method (PLS-SEM) was adopted to analyse the proposed model. The method is a practical approach to analyse relationships of a complex construct with many indicators, latent variables, and constructs (Hair et al., 2011). PLS-SEM is more accurate in analysing the reliability and validity in a model with moderating effect (Marcoulides et al., 2009). PLS-SEM can analyse the measurement and structural model as well as the model's prediction competency (Henseler et al., 2009).

4.1 Research setting

In the present research, when questions were modified and confirmed by experts, the questionnaires were used . Minor changes were made to the questionnaires based on the pre-test. Finally, 48 questions were included and submitted to the participants. The main dimensions were knowledge sharing, innovation climate, knowledge acquisition, LMX, organisational affective, normative and continuous commitment, employee retention. Measurements are evaluated on a five- point Likert scale (i.e., "1"=strongly disagree; "5" = strongly agree). Furthermore, five questions about gender, age, level of education, job title, and years of experience were included in the questionnaire (see table 1).

Table1. Research Questionnaire

Variables	Questions	Reference
Organizational commitment	**Organizational Affective Commitment Scale items (OAC)** OAC1. I enjoy spending the rest of my work life with Parsian Hotel Group. OAC2. I gladly discuss Parsian Hotel Group with others communities. OAC3. I account Parsian Hotel Group's problems are my own. OAC4. I could quickly become accustomed to working for another Hotel than Parsian Hotel Group (Reverse). OAC5. I don't assume, I am 'part of the family' at Parsian Hotel Group (Reverse). OAC6. I don't assume, I 'emotionally attached' to Parsian Hotel Group (Reverse). **Organizational Normative Commitment (ONC)** ONC1. I believe that nowadays employees move from one firm to another too often. ONC2. I do not believe that an individual should always be firmly loyal to the firm she/he is working in (Reverse). ONC3. I keep working for Parsian Hotel Group because I opine loyalty is an important issue and I feel a great sense of moral obligation to stay at my current job. ONC4. I would not consider job offer from another firm, even for better job, because I feel it is not right to leave Parsian Hotel Group. ONC5. "Things were better" at the time when employees remain with one firm for most part of their careers life. ONC6. I do not support being 'company man' or 'company woman' as a justifiable decision anymore (Reverse). **Organizational Continuance Commitment (OCC)** OCC1. I am not afraid of the consequences of accepting one job offer from another firm (Reverse). OCC2. It would not be easy for me to leave Parsian Hotel Group right now. OCC3. Leaving Parsian Hotel Group now is too costly for me. OCC4. Staying with Parsian Hotel Group for me at the moment is due to both necessity and desire. OCC5. If I decide about terminating my job in Parsian Hotel Group, only a few options would be available to me. OCC6. Benefits offered by another firm may not be on par with what I have here.	**Allen & Meyer, 1990**
Employee Retention Intention	R1. I am seeking to find another job outside of Parsian Hotel Group. (reversed) R2. I would switch to another firm with an excellent management. (reversed) R3. I would be willing to accept another job offer with even slightly better job position. (reversed) R4. As soon as I find a better paid job in another firm, I would leave my job at Parsian Hotel Group. (reversed)	**Mak & Sockel, 2001**
Knowledge Sharing	AKS1. I believe that it is prominent to share knowledge with Parsian Hotel Group for the benefit of all. AKS2. I happily share my knowledge in the case of requests of other Parsian Hotel Group members. AKS3. I would be glad to share my knowledge with other colleagues at Parsian Hotel Group. AKS4. I opine that co-workers should share knowledge only when they request it. (reversed) AKS5. I support the idea that "sharing is caring". AKS6. Sharing information with peer workers should be avoided when it is possible. (reversed)	**Yuen & Majid, 2007**
Knowledge Acquisition	KA1- I am actively seeking information about changes in the marketplace. KA2- I take delight in learning new ideas to improve the use of knowledge concerning my job. KA3- I feel comfortable asking others for data to make it possible for me to handle my job better.	**Darroch, 2003; Hwang et al., 2018**
Innovation Climate	ICI1. Applying new ways to do our job is accepted and tolerated in Parsian Hotel Group. ICI2. In Parsian Hotel Group, workers are willing to seek new and unusual solutions. ICI3. I would receive our manager's support if we wanted to try new methods to do our job. ICI4. I can discuss the methods and procedures openly within our workgroup. ICI5. More often, we receive the resources needed to do our job. ICI6. My line of work is currently challenging. ICI7. I feel free to make a change in how I am carrying out my job. ICI8. Usually, I have too much on my plate to handle in too little time (Reverse). ICI9. All in all, the working environment in Parsian Hotel Group is innovative. ICI10. In general, the working environment in Parsian Hotel Group is effective.	**Amabile et al., 1996**
LMX	LMX1. I usually know how to satisfy my manager or supervisor with what I do at my job. LMX2. My manager or supervisor understands my job requirement and problems. LMX3. My manager or supervisor recognize my potential. LMX4. My manager or supervisor uses his or her authority to help me to overcome my work issues. LMX5. My manager or supervisor uses his or her authority to "bail you out" at his or her expense. LMX6. I would defend my manager or supervisor decision in his/her absence. LMX7. I perceive my working relationship with my manager or supervisor as favourable.	**Graen & Uhl-Bien, 1995**

4.2 Data Analyses

The reliability of the questionnaires content analysed and confirmed by experts. For the present model, in pre-test, Cronbach's alpha coefficient is 0.912. The contents of 250 questionnaires were analysed to evaluate the proposed model. To fit assess the measuring model, three criteria such as reliability, convergent, and discriminant validity are extracted. Reliability is assessed by factor loads in terms of Cronbach's alpha and composite reliability and convergent and discriminant validity by assessing average variance extracted (AVE) factor (Chin, 1998). The structural model latent variables are examined along with the relationships between them. To assess the structural fit criteria such as R^2 and Q^2 will be considered. The general model fit analysis includes measuring model and structural model and when it is confirmed, fit assessment is completed. It is indicated under the goodness of the fit (GOF) criteria (Tenenhaus et al., 2005).

4.3 Respondents

The study sample in the present paper is 250 employees of Parsian Esteghlal International Hotel. Table 2 summarised the demographic characteristics of the responders.

Table 2. Demographic profile of responders (N=250)

Characteristics of The Responders		Frequency	Percent
Gender	Female	109	44
	Male	141	56
Age	Under 25	40	16
	Between 26-35	64	25.6
	Between 36-45	76	30.4
	Between 46-55	40	16
	over56	30	12
Education	Associate and Less	11	4.4
	Bachelor	103	41.2
	Master	116	46.4
	PhD	20	8
Job Titles	Junior Staff	115	46
	Head Waiter	60	24
	Supervisor	50	20
	Manager	25	10
Years of Experience	Less than 1 year	15	6
	1–5 years	85	34
	6–10 years	120	48
	Over 10 years	30	12
Total		**250**	**100**

Descriptive statistics have been shown in table 3. Data average fluctuates from 3.3 to 4.2. Organisation normative commitment has a maximum average and organisation affective commitment has a minimum average. The data range is high and less than 4. Innovation climate variable has the least range and the organisation normative commitment variance is less than other variables which imply the unity of opinion of participants. Mode indicate that majority of participants choose strongly agreed within the options.

Table 3. Construction Variables Descriptive Analysis

Construction Variables	Qty	Ave	Mod	SD	Var	Range	Min	Max
Organisation affective commitment	250	3,396	5,000	1,312	1,720	4,000	1,000	5
Organisation continuous commitment	250	3,978	5,000	0,827	0,686	4,000	1,000	5
Organisation normative commitment	250	4,172	5,000	0,717	0,513	4,000	1,000	5
Employee retention intention	250	4,073	5,000	0,813	0,662	4,000	1,000	5
Knowledge acquisition	250	3,615	5,000	1,136	1,291	4,000	1,000	5
knowledge sharing	250	3,857	5,000	0,995	0,912	3,667	1,333	5
Innovation climate	250	4,000	5,000	0,971	0,942	3,400	1,600	5
LMX	250	3,558	5,000	1,261	1,590	4,000	1,000	5

5. Measurement Model Fit Analyse

The relation between latent variables and constructs exhibit in loading factor. Loading Factor less than 0.3 is not desirable, between 0.3 and 0.6 is approvable, and above 0.6 is desirable (Kline, 2011). However, the main criterion to analyse the loading factor is t-value statistics. If the t-test statistic is higher than the critical value of $t_{0.05}$ i.e. 1.96, thus loading factor is statistically significant.

According to the measurement model shown in table 4, all loading factors are higher than 0.3, which indicate acceptable correlations between observable variables and their latent variables. Also, according to measurement model bootstrapping results, t-statistic for all variables is higher than a critical amount of 1.96.

Cronbach's alpha higher than 0.7 is approvable. Composite reliability measures the sufficiency of items of latent factor (Werts et al., 1974), with Composite reliability higher than 0.7, the internal consistency is confirmed (Nunnally, 1994). Composite reliability is more reliable criteria than Cronbach's alpha (Vinzi et al., 2010). As per table 4, Cronbach's alpha and composite reliability of all variables are in acceptable level.

Table 4. Measurement Model

Variables	Indicator	Factor loads	Significance factor	Cronbach's Alpha	Composite Reliability
Organizational Commitment Organisational Affective Commitment Organisation continuous commitment Organisation normative commitment	OAC OCC ONC	0.941 0.958 0.960	104.720 190.473 185.888	0.949	0.967
Employee Retention Intention	R1	0.905	56.176	0.821	0.884
	R2	0.897	62.513		
	R3	0.861	49.055		
	R4	0.540	6.408		
Knowledge Acquisition	KA1	0.879	67.882	0.683	0.824
	KA2	0.797	25.546		
	KA3	0.656	10.308		
Knowledge Sharing	AKS1	0.868	49.393	0.912	0.933
	AKS 2	0.860	34.622		
	AKS 3	0.853	43.595		
	AKS 4	0.882	51.441		
	AKS 5	0.884	51.119		
	AKS 6	0.652	15.092		
Innovation Climate	ICI1	0.744	24.739	0.941	0.952
	ICI2	0.831	27.745		
	ICI3	0.399	5.754		
	ICI4	0.841	34.357		
	ICI5	0.860	43.121		
	ICI6	0.851	39.026		
	ICI7	0.887	53.087		
	ICI8	0.885	51.872		
	ICI9	0.889	48.452		
	ICI10	0.893	54.599		
LMX	LMX1	0.806	27.184	0.932	0.945
	LMX2	0.743	20.733		
	LMX3	0.904	63.591		
	LMX4	0.866	48.746		
	LMX5	0.865	53.986		
	LMX6	0.916	64.409		
	LMX7	0.798	28.971		

Convergent validity measures the extent of correlation of multiple indicators of the subjected construct and it is reported in term of AVE factor and should be higher than 0.5 (Fornell & Larcker, 1981). As table 5 shows all AVEs are higher than 0.5, which verify the convergent validity of variables.

Discriminate validity manifests the degree to which the particular construct has digressed from other constructs. To analyse the discriminant validity, the square root of AVE should be extracted (Fornell & Larcker, 1981). Numbers on the main matrix diagonal in table 5 show the discriminant validities. As table 5 reported, discriminant validities are desirable.

Variables	AVE	OC	LMX	IC	ER	KA	KS
Organizational Commitment (OC)	**0.908**	**0.953**					
LMX	**0.713**	0.718	**0.845**				
Innovation Climate (IC)	**0.673**	0.699	0.618	**0.820**			
Employee Retention Intention (ER)	**0.665**	0.632	0.709	0.765	**0.815**		
Knowledge Acquisition (KA)	**0.612**	0.625	0.678	0.672	0.653	**0.783**	
Knowledge Sharing (KS)	**0.701**	0.786	0.708	0.784	0.724	0.653	**0.837**

Table 5. Convergent and Discriminant Validity

6. Structural Model Fit Assessment:

R^2 is the criteria to connect the measurement model to the structural model and indicate the effect of an exogenous variable on the endogenous variable (Chin, 1998). R^2 measured to 0.19, 0.33 and 0.67 is considered as weak, moderate and substantial, with higher R^2 means more appropriate model fit (Henseler et al., 2009).

Structural model quality is measured by Q^2. Q^2 is measured by blindfolding method and shows the reflective endogenous variables prediction power or accuracy of the adjusted model (Henseler et al., 2009) and value greater than zero is approvable (Stone, 1974; Geisser, 1975). Q^2 amounted to 0.02, 0.15 and 0.35 is considered as weak, moderate and substantial (Henseler et al., 2009). In table 4, R^2 and Q^2 of the model have been indicated.

GOF is a criterion to assess the general model performance and specify whether the model is fit or not (Tenenhaus et al., 2005). GOF amounted to 0.01, 0.25 and 0.36 is considered as weak, moderate and substantial.

As per table 6, GOFs calculated from three steps analysis is higher than 0.36, which indicates the general model is substantial.

Table 6. Structural Model Quality Indicators

Step	Variables	R^2	Q^2	GOF
Step 1	ER	0.401	0.248	0.652
	KA	0.525	0.302	
	KS	0.841	0.547	
Step 2	ER	0.511	0.315	0.692
	KA	0.663	0.376	
	KS	0.842	0.547	
Step 3	ER	0.528	0.321	0.655
	KA	0.676	0.373	
	KS	0.856	0.554	

Harman's single-factor approach was applied to test common method variance. The common method bias verifies the internal validity of the self-reported survey, which is emerged if the majority of variances loaded in unique factor for all questionnaire items (Sharma et al., 2009). As per Kaiser Criteria, four factors were apparent in the un-rotated factor structure that explained 76.524% of the variance. In the present study, the first-factor variance is 45%, indicating that common method variance is not confounding the interpretation of the study result.

7. Study Hypothesis Test

The structural analysis has been applied in three steps by PLS. In step 1, the connections between main variables KS, KA, ER, OC without moderators (IC, LMX) are analysed; in step 2 direct impacts of moderators (IC, LMX) also are assessed, and in step 3, the model considering OC×IC and OC×LMX effects are tested.

OC effect on ER has been analysed in 3 steps. As per table 7 in the first step, OC to ER analysis (β=0.63, p<0.001) shows a positive and significant effect of OC to ER (H4 supported). In step 2, considering the LMX the test results are as follows; OC on ER (β= 0.16, p<0.05), LMX on ER (β= 0.58, p<0.001) which indicate the positive and significant effect of OC and LMX on ER. And finally, in step 3, entering the LMX and analysing OC×LMX on ER reports (β= 0.14, p<0.05) which specifies the positive and significant effect of OC×LMX on ER (H5-1 supported).

OC effect on KA has been analysed in 3 steps. As per table 6, in the first step OC to KA analysis (β=0.72, p<0.001) indicates a positive and significant effect of OC to KA (H2 supported). In step 2, considering the IC, the test results are as follows; OC on KA (β= 0.36, p<0.001), IC on KA (β= 0.52, p<0.001) which show the positive and significant effect of OC and IC on KA. Finally, in step 3 analysing OC×IC on KA result is (β= 0.14, p<0.05) which specifies the positive and significant effect of OC×IC on KA (H2-1 supported).

OC effect on KS has been analysed in 3 steps. As per table 6, in the first step results OC to KS (β=0.29, p<0.001), ER to KS (β=0.36, p<0.001) and KA to KS (β=0.38, p<0.001) show that positive and significant effect of OC to KS, ER to KS, and KA to KS (H1, H5 and H3 supported). In step 2, considering the IC, results are as follows, OC on KS (β= 0.27, p<0.001)، KA on KS (β=0.35, p<0.001), and ER on KS (β= 0.34, p<0.001) which indicate the positive and significant effect of OC, KA and ER on KS. However, the analysis hasn't shown the direct positive and significant effect of IC on KS. Finally, in step 3, considering the moderating IC, analyses are as follows: OC on KS (β= 0.29, p<0.001), ER on KS (β= 0.32, p<0.001), KA on KS (β= 0.32, p<0.001) , OC×IC on KS (β= 0.13, p<0.05) which imply that IC reinforces the relation between OC and KS (H1-1 supported). Figure 2 demonstrated step 1, figure 3 related to step 2 and figure 4 is the result of step3.

Tables 7. Structural Model Fit Asses and Moderators

Model Paths	Step 1		Step 2		Step 3	
	β	R^2	β	R^2	β	R^2
To ER						
From OC	0.63***	0.4	0.16*	0.51	0.21*	0.53
From LMX			0.58***		0.5***	
From OC×LMX					0.14*	
To KA						
From OC	0.72***	0.53	0.36***	0.66	0.36***	0.68
From IC			0.52***		0.52***	
From OC×IC					0.14*	
To KS						
From OC	0.29***		0.27***		0.29***	
From ER	0.36***	0.84	0.34***	0.84	0.32***	0.86
From KA	0.38***		0.35***		0.32***	
From IC			0.06		0.09	
From OC×IC					0.13*	
p<0/05* p<0/01 p<0/001***						

Figure 2. Model Analysis - Step 1

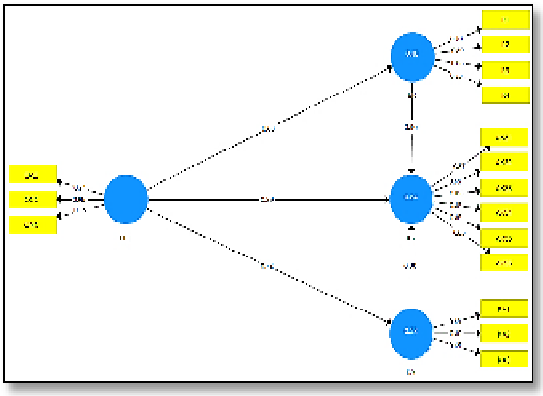
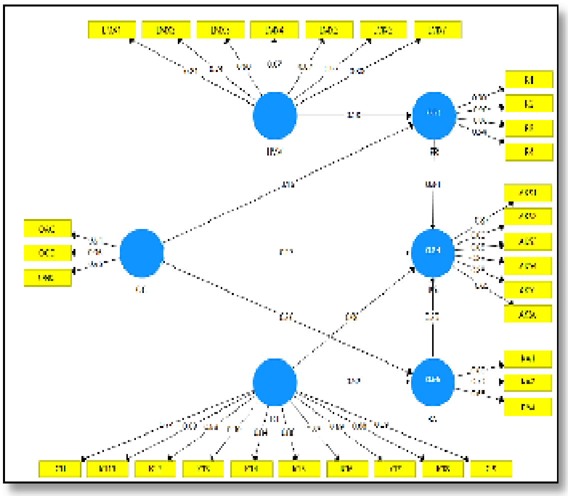


Figure 3. Model Analysis- Step 2



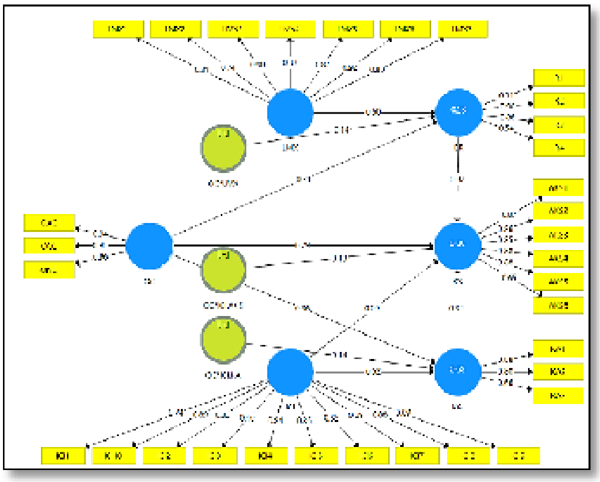


Figure 4. Model Analysis- Step 3

8. Theoretical and managerial implications

The present research extends the management literature on KM practices. The present survey results would benefit academicians and managers in various ways.

First, the present research confirms the positive impact of organisational commitment on employee retention, in the same line with the findings of Saputra and Riana (2021), Sari and Gustiayumanuatidewi (2020), and Yao et al. (2019). Meanwhile, the LMX positively affects employee retention, which is similar to a finding reported by Tubay (2019). Furthermore, this research covers the gap in the literature by demonstrating the LMX as a moderator between commitment and employee retention. Accordingly, the organisational commitment and desired LMX influence employees' intention to keep working in the company. Leaders can contribute to KM by retaining employees. A sense of affiliation with a firm, feeling of honour of working in a firm, and respect for management are conducive to employee retention in the hospitality context (Ineson & Berechet, 2011).

Second, organisational commitment inspires knowledge acquisition practices, an advanced finding in the KM studies. Committed employees are more risk-taker and tend to obtain information and knowledge about their job context. In addition, organisational commitment is positively linked to knowledge sharing, which agrees with Nielsen et al.'s (2011) finding. Compared to the other commitment dimensions, employees' normative commitment has the highest mean score. Accordingly, our research finding verifies Meyer and Parfyonova’s (2010) proposal indicating normative commitment as a more dominant aspect than the other dimensions. However, the affective commitment is reported to hold the most robust nexus to the knowledge sharing. This finding is in line with Marques et al. (2019) and Rasdi and Tangaraja (2020). Meanwhile, knowledge acquisition positively affects knowledge sharing, consistent with Oye et al. (2011) and Darroch's (2003) research findings.

Given the crucial role of organisational Commitment on KM implementation and the effect of HRM practices on employee commitment (Gaertner & Nollen, 1989; Kinicki et al., 1992; Ogilvie, 1986), employees’ attitude toward KM fulfilment can be shaped using the HRM practices. To keep the spirit of affective commitment, the organisation should melange it with trust, in the form of fair rewards and appreciation to employee contributions since trust-based affection can engender knowledge sharing (Naeem et al., 2019). Employees' satisfaction will lead to commitment in all three aspects and, consequently, to employee loyalty (Yao et al., 2019). Job conditions, interpersonal relationships, employee empowerment, assigning awards to employee's accomplishments (Mowday et al., 2013), and education (Mukherjee et al., 2009) would eventually reinforce employee loyalty (Zeithaml et al., 1990).

In addition, we found highly experienced employees with managerial positions are more committed to a firm, as Kim & Mueller (2011) formerly stated, while younger employees (under 25 and 26–35) have the lowest level of organisational commitment. It emphasises the significant role of age in developing commitment to the organisation. To decline the turnover among non-management employee, some measures such as educating employee on organisational mission, vision, goals, alongside justified rewards and compensation sub-systems and finally promotion are found to be effective (Moncarz et al., 2009).

Furthermore, hotels in Iran usually pay low salaries to their young and new employees than other industries. Raising fixed salaries, enhancing fringe benefits, compensation, and improving work conditions could positively be associated with new employee commitment (Guan et al., 2014).

Moreover, most Iranian young hotel staff, particularly at the operational level, are migrants dealing with financial and cultural adaptation challenges in their working environment, associated with stress and physiological tension. Managers, therefore, should also consider the psychological needs of such employees. Research on the hotel industry shows that close attention to employees' independent personalities, beliefs, values, and self-awareness will reinforce their normative commitment. Huang and Rundle-Thiele (2014) suggested that the above approaches can influence employees' performance and benefit the organisational outcome, especially in the hospitality sector. Ineson et al. (2013) reported that social involvement in the workplace is verified to engender a more significant impact than that of monetary rewards on an employee to develop loyal behaviour. Establishing a sense of ownership for such workers boosts their organisational affective commitment.

Third, as a moderator between organisation commitment and knowledge sharing and acquisition, the innovation climate reinforces the relations. Moreover, innovation climate influences knowledge acquisition directly and positively. It is inferred that with an atmosphere encouraging innovation, the individuals' tendency toward knowledge acquisition is expected. However, our study did not reveal the same connection between knowledge-sharing behaviour and innovation climate. It could be construed to share the knowledge personal traits are also involved. Furthermore, Zarraga & Bonache (2003) stated that some other factors, including (a)friendly relationships, the degree of an employee's perception of interpersonal communication and cooperation and (b)fairness; the degree of an employee's perception of the extent of fairness within an organisation also are of paramount importance to share the knowledge as well as innovation climate.

9. Conclusion

The conceptual framework proposed in the present study suggests the consequences of commitment in KM. According to the findings, commitment plays a critical role in implementing the KM activities. Research confirmed the impact of commitment on knowledge acquisition, knowledge sharing, and employee retention intention. Knowledge acquisition positively links to knowledge sharing. As a moderator, LMX is positively associated with employee retention intention. Meanwhile, employee retention intention impacts positively on knowledge sharing behaviour. Moreover, innovation climate as a moderator between commitment and knowledge sharing and acquisition acts favourably regarding employee's involvement in KM.

10. Limitations and Future Study Suggestions

Although this study was carried out at an Iranian hotel and culture, the study outcomes may be different if conducted in another scope. The results may be varied if the country setting is changed. Other services such as medical sectors, consulting firms, or creative agencies, to name a few, also can be surveyed. Organisation brand image is confirmed to be a factor with a positive impact on employee commitment; therefore, the effect of brand image on the commitment to the KM system can be studied. The presence of old staff could also be examined as a factor that motivates the new employees to see themselves as long-time workers in the organisation. It can motivate them to be more open in terms of commitment to KM. For future study, the effects of the leader style on success of KM implementation can be surveyed. Leaders as role models in commitment to KM motivate employees to be more committed to the KM system.

Individuals should view knowledge sharing as a routine in their job environments (Ullah et al., 2016). Accordingly, it should be detected whether leader activities and presence in social networks such as Twitter can encourage employees to act favourably toward KM practices. Meanwhile, via social networks, knowledge sharing is an everyday matter, and individuals are much more familiar with the knowledge sharing concept. The future study may consider the employees general predisposition toward knowledge sharing. Moreover, it could be investigated whether organisation pages in social networks such as Facebook and Twitter imply information transparency and availability of information, and it can aid the KM implementation. Further research is recommended to examine the effects of other factors such as encouraging systems, lifestyle, activities, ethics, work-life balance, and personality traits (e.g., pro-activeness in information acquisition) on complying with KM.

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A QFD-TRIZ Hybrid Method for a Hygiene Product

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Abstract

This study examined the use of the QFD- TRIZ hybrid method in Inclusive Design. The requirements of the vulnerable groups are considered and applied to the design while redesigning the product. The effect of this method in redesigning adult diapers has been investigated with a focus on maintaining the elderly dignity and minimizing the caregivers' involvement in the nursing process to maintain respectful life for the elderly. In this paper, the product needs were identified by interviewing older adults and their caregivers. Then, the relationship between the elderly needs with their corresponding technical characteristics and the priority of these needs in the product was determined using the QFD method. The TRIZ Contradiction Matrix was used to identify engineering parameters in order to find ideas and create a new concept product design. Inclusive Design assures the manufacturer that the product is highly flexible and can be used in all consumer groups.
Keywords: Inclusive Design, Quality Function Deployment (QFD), Theory of Inventive Problem Solving (TRIZ)

1. Introduction

Two major trends have led to significant growth in Inclusive Design: First, population growth, and second, the assimilation of disabled people into society. According to the United Nations statistics, the world's population of people aged over 60 will be doubled by 2025, with a sharp rise from 542 million in 1995 to about 1.2 billion. Moreover, by 2030, more than 60 countries will host at least 2 million people over the age of 65 (Powell, 2010). In Iran also, the population aging index indicates a significant incremental trend. The predictions show that in 2015, the population of people aged over 60 will be 7% of the world's whole and by 2035 this number will reach 14.77%. It is also expected that by 2055, this number will reach 27.33 percent of the world population. According to the researches in the field of demography, the growth of the elderly population in Iran will be very remarkable from 2035 onwards (Kiani et al, 2010).

Inclusive Design is a general design approach in which designers ensure that their products and services meet the needs of users, regardless of their gender, ability, or age (Clarkson, 2015). Therefore, it can be claimed that Inclusive Design helps with enhancing the product capabilities (Luck, 2018).

Generally, considering social factors as parameters applied in designing the product, regardless of the type of product or industry, is of particular significance and has always been recognized as a limitation in researches in the domain of product and service design. Among these studies, we can refer to the articles such as "A benchmark-based method for sustainable product design" (A case study on wheelchair) by Hosseinpour et al. (2015), "A framework for sustainable product design: a hybrid fuzzy approach based on quality function deployment for the environment" (A Case Study on Transformer) by Younesi and Roghanian (2015), "Integration of green quality function deployment and fuzzy theory: a case study on green mobile phone design." by Wu and Ho (2015), "Evaluation of products at the design phase for an efficient disassembly at end-of-life" (A case study on. Jet aircraft) by Sabaghi et al. (2016), "A customization-oriented framework for the design of sustainable product/service system." (M elevator company) by Song and Sakao (2017) and so on.

The combination of QFD and TRIZ methods was used to redesign adult diapers with a focus on the social function of the product (maintaining the elders' dignity and the minimum involvement of caregivers in the nursing process in order to maintain respect for the elderly). This paper is organized into five sections: the first section includes an introduction, the second section contains a review of literature, the third section discusses the model implementation method, the fourth section includes the findings of the study, and the fifth section presents the conclusion.

2. Literature Review

New product development is usually defined as a set of activities that begins with identifying user needs and understanding market opportunities, and ends with the production, sale, and delivery of the product to the end-user. Product development is a knowledge-based activity by which the user needs are turned into the technical requirements of the product. Communication with customers and identifying their needs is a continuous and permanent action with the purpose of updating the products, and this aim is achieved by redesigning the products in reasonable periods of time. While changing the product parameters to meet a need, other features and functions of the product might be affected and weakened. Moreover, engineers can rarely claim that the best option has been selected and all possible design ideas have been considered in the design phase. Therefore, in order to overcome the aforementioned challenges in the process of product development, a combination of Quality Function Deployment (QFD) and Theory of Inventive Problem Solving (TRIZ) methods has been used.

By identifying the needs of all user groups, Inclusive Design approach leads to the creation of extensive capabilities in the product and helps to eliminate possible limitations in the product, and therefore it affects specific people's access (older adults, people with disabilities, etc.) to the product. Using the combined approach in Inclusive Design can help with identifying the new needs of vulnerable groups and turning them into product features. This is because QFD has always been a method for converting customer needs and voice into product features, and TRIZ has been used to identify potential contradictions and provide ideas to achieve practical solutions.

2.1 QFD Method

Quality Function Deployment (QFD) is a powerful tool for converting the customer's voice (qualitative needs) into engineering Characteristics (quantitative design parameters). QFD is widely used in making decisions about product design and production (Chan & Wu, 2002). This method provides an appropriate understanding of customer expectations in the process of designing and developing products, services, and processes, and it helps with satisfying their expectations by taking account of the customers' real needs (Aydarov et al, 2018). The Quality Function Deployment is able to turn customer needs into practical functions. Its whole process usually consists of four steps. The first step (customer needs planning matrix for translating customer needs into product design requirements) alone acts as a regular method and it is enough to translate the customer's voice into engineering Characteristics (Yenradee & Akkawuttiwanich, 2018). House of Quality matrix is the first and foremost building block of QFD. As shown in Figure 1, a simple example of House of Quality is a combination of "WHATs" and "HOWs”. "WHATs" consists of the customer's requirements and expectations from the product (voice of the customer) and "HOWs" expresses the way of representing the customer's expectations in the product (Park et al, 2012). At this step, while determining the relationship between customer requirements and the product technical characteristics in the relationship matrix, the kind of correlation among the product technical characteristics is also determined and indicated in the roof of the House of Quality.

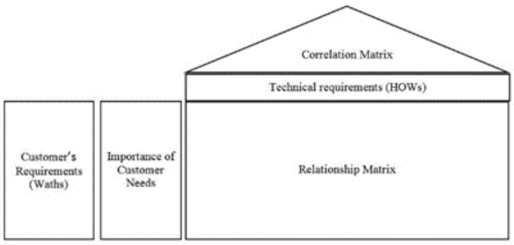

Fig. 1. House of Quality (Park et al, 2012).

The main advantage of Quality Function Deployment is focusing on customers for product innovation. This tool has been defined as an important method for improving design quality and customer satisfaction and translating customer needs into design goals (Djekic et al, 2017). The most important advantages of using QFD are as follows (Dikmen et al, 2005):

- **Accurately collecting and identifying the customer needs:** This tool provides a regular method for collecting and identifying the customer needs. Accordingly, the customer expectations are collected in the early stages and they are used to provide the appropriate design solutions.

- **Better planning:** QFD helps with tracking the customer expectations from the beginning to the end of the project, and any potential distortions can be verified in a timely manner.
- **Strengthening relationship and synchronization:** QFD requires team organization and interaction to collect the customer needs and turn them to the design goals in an accurate manner. Therefore, it directs the team to do their job using simultaneous procedures and processes.
- **Reducing uncertainty:** The initial identification of customer expectations minimizes the uncertainty as the project progresses.
- **Reducing the time for product development and redesign:** From the very beginning, the project teams are exactly aware of what they can produce

2.2 TRIZ Method

According to the principles of TRIZ method, the evolution of technical systems is not accidental, instead it is predictable based on certain rules. Since technical systems follow repetitive patterns in the long run, this pattern is regularly used to develop products. The design goal is to meet the needs of new and creative methods. Thus, the TRIZ Contradiction Matrix has been used to eliminate possible technical contradictions among product technical requirements by providing solutions based on the principles of innovation.

The contradiction arises when a designer has to choose between two different features. Technical contradictions arise when opposite states must be present in a product at the same time (Gadd, 2011). One of the most important tools in TRIZ is the Contradiction Matrix. One of the reasons for the development of systems is a flaw in their current function. Contradictory functions between system parameters usually make designers think about redesigning and modifying the current design. TRIZ seeks to resolve these contradictions by focusing on the system's contradictory functions and using innovative principles. By applying the Contradiction Matrix, these contradictions are identified and the proposed creative principles of TRIZ make it possible to solve the problem.

Creative principles in the ideation phase help engineers consider the best ideas for a new product design by examining the possible aspects. The Inventive Problem-Solving method has been recognized by many scientists as a systematic approach that offers a logical approach to provide creativity for innovation and problem solving (Ilevbare et al, 2013). As shown in Table 1, Altshuller proposed forty creative principles by examining the different inventions registered in the world. According to Altshuller, innovation is a systematic process that follows specific patterns of evolution. Recent research shows that TRIZ speeds up generating ideas for new products and services and it improves quality between 70 to 300 percent (Naveiro & Oliveira, 2018).

Table 1. Inventive principles (Naveiro & Oliveira, 2018).

N	Inventive principle	N	Inventive principle
1	Segmentation	21	Skipping
2	Extraction	22	Convert Harm into Benefit
3	Local Quality	23	Feedback
4	Asymmetry	24	Intermediary
5	Consolidation	25	Self-service
6	Universality	26	Copying
7	Nesting	27	Dispos
8	counterweight	28	Replacement of mechanical system
9	Preliminary anti-action	29	Pneumatics and hydraulics
10	Preliminary action	30	Flexible shells and thin films
11	Cushioning in Advance	31	Porous materials
12	Equipotentiality	32	Color changes
13	Do it in Reverse	33	Homogeneity
14	Spheroidality	34	Discarding and recovering
15	Dynamics	35	Transformation of Properties
16	Partial or excessive actions	36	Phase transitions
17	Another dimension	37	Thermal expansion
18	Mechanical vibration	38	Strong oxidants

Engineering parameters are the physical values involved in technical contradictions which depending on the problem should be increased, minimized, or kept at a certain value. As shown in Table 2, Altshuller has proposed technical parameters to describe the characteristics or functions of engineering systems.

2.3 Inclusive Design

The term "Inclusive Design" was first used in 1994 and it has been increasingly expanded since then. Its primary focus was on the global implications of population aging and disability for design challenges and market opportunities, and it was also an effort to create a link between design and social needs. Inclusive Design is recognized as a general design approach that its designers make sure that their products and services meet the needs of a wide range of potential users, re-

gardless of their age or ability. Inclusive Design is meant for all people in Europe and the United States. Figure 2 shows the origins of influences and ideas about Inclusive Design in both the horizontal spectrum (focusing on age and disability) and the vertical spectrum (private sector and government actions) (Clarkson & Coleman, 2015). Inclusive Design is a type of design with the aim of the maximum use of products with the most possible social function. This approach specifically focuses on the disabled and the elderly.

Table 2. Engineering parameters (Naveiro & Oliveira, 2018).

N	Engineering parameters	N	Engineering parameters
1	Weight of moving object	21	Power
2	Weight of nonmoving object	22	Waste of energy
3	Length of moving object	23	Waste of substance
4	Length of nonmoving object	24	Loss of information
5	Area of moving object	25	Waste of time
6	Area of nonmoving object	26	Amount of substance
7	Volume of moving object	27	Reliability
8	Volume of nonmoving object	28	Accuracy of measurement
9	Speed	29	Accuracy of manufacturing
10	Force	30	Harmful factors acting on object
11	Tension, pressure		
12	Shape	31	Harmful side effects
13	Stability of object	32	Manufacturability
14	Strength	33	Convenience of use
15	Durability of moving object	34	Repairability
16	Durability of nonmoving object	35	Adaptability
17	Temperature	36	Complexity of device
18	Brightness	37	Complexity of control
19	Energy spent by moving object	38	Level of automation
20	Energy spent by nonmoving object	39	Productivity

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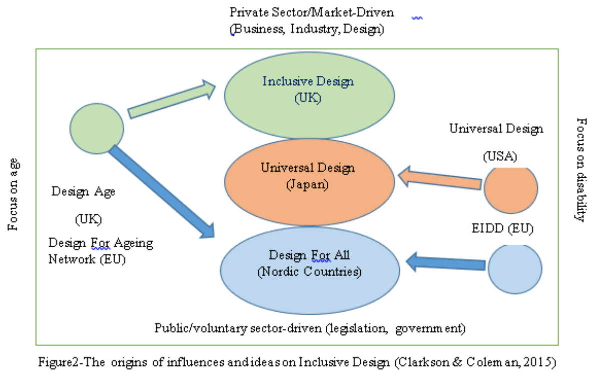

Fig. 2. The origins of influences and ideas on Inclusive Design (Clarkson & Coleman, 2015)

2.5 Inclusive Design of Hygiene Products with the Help of QFD-TRIZ: A Research Gap and an Innovation

By reviewing the literature on product design, it is clearly observed that the combination of QFD and TRIZ methods based on customer needs has been used to improve the product-service design. QFD makes it possible to translate technical characteristics into design features; however, some contradictions arise from QFD evaluation. In the correlation matrix, technical requirements that are negatively correlated with each other and are identified; they are called technical contradictions. Technical contradictions arise when opposite states must be present in a product at the same time. For example, the parameter of being automatic and cost-effective in a product is a technical contradiction, as you need to increase the level of technology in your product, but you should not increase the cost of the product in such a way that stops users from buying. Therefore, in order to strengthen the features arising from QFD, a systematic analysis based on TRIZ is performed to provide inventive solutions. In the related literature, some studies can be found about the integration of QFD and TRIZ. Specifically, you could refer to the following studies: Kim and Yoon (2012) in a study entitled "Developing a process of concept generation for new product-service systems: a QFD and TRIZ-based approach", predicted the proposed method of a carpooling service company. In the first stage, they studied the relationship between customer needs and product services and in the second stage, the relationship between service concepts and product features was identified. The most important concept at this stage is paid services. With the development of electronic payment systems, payment services will improve, but this system will make information more complex. This contradiction is resolved by the inventive principles of TRIZ. The principle of "intermediary" creativity proposes using an intermediary payment system for payment services. In “Development of an innovative conceptual design process by using Pahl and Beitz’s systematic design, TRIZ and QFD” (A case study on punching machine) by Mayda and Borklu (2014), TRIZ is used as a problem finder, a solution trigger, and a solution improver, which is an original contribution. In this research, QFD is used for converting customer needs into design parameters that are further taken as criteria in the evaluation step, which is another original contribution of this study. The applicability of the proposed model is demonstrated through a case study. The case study shows that the proposed model allows designers to find easily innovative and customer-centered solutions. In “Printer CAD: a QFD and TRIZ integrated design solution for large size open molding manufacturing” by Francia et al. (2017), the open molding technique has been discussed in order to update the current manufacturing technique in order to meet the emerging sustainable strategies. Through the integration of QFD and TRIZ, an innovative design method has been assessed for enhancing the manufacturing process by means of computer-aided engineering devices. Printer CAD is a project that aims to manage additive and subtractive techniques, applied to complex and large-scale products, by means of open-source software with an integrated module. Its aim is to enhance the CAD, CAM, and slicing for the intercommunication of 3D printer languages. In a study entitled “QFD and TRIZ integration in product development: a model for systematic optimization of engineering requirements (A case study on mortar)." by Naveiro and De Oliveira (2018), they are used to meet the most appropriate user needs and technical requirements in the design of a type of mortar, and the use of patent documents. As a result, their proposed ideas for "design of aerodynamic fins at the end of the mortar with retractability" cause longitudinal rotation, by integrating several technical requirements in the design of value-added products (increase mortar range - increase accuracy). The proposed model is generally proposed for the development of the product concept and it is also a useful method for the evolution of the modernization process. These are examples of QFD and TRIZ combinations in product design. Table 3 lists the studies conducted in the field of product design, using QFD, TRIZ, the combination of QFD and TRIZ, or the combination of each of them with any other tools. On the other hand, according to the case study in these researches, it can be observed that most of the studies have been conducted on industrial products.

In the context of designing sanitary and health care products, most of the studies are in specialized fields such as textile, chemical engineering, and so on. In this type of design, according to the designer's specialized orientation, the focus is on improving one of the product parameters. In some studies, after changing one product technical parameter, the performance of the applied changes was evaluated through the use of another tool. For example, in the study by Mendoza et al. (2019), entitled “Improving resource efficiency and environmental impacts through novel design and manufacturing of disposable baby diapers” the new design of disposable diapers for children was initially performed using petrolatum-based adhesive gels in order to reduce wastage and environmental effects.

Table 3. A review of case studies on product design

Author(s) /Year	Issue	Tools	Case study
Naveiro & de Oliviera (2018)	A model for systematic optimization of engineering requirements	QFD & TRIZ	mortar
Francia et al (2017)	Printer CAD: QFD and TRIZ integrated design solution for producing large size molds	QFD & TRIZ	Production of large molds
Wang et al (2017)	Designing a food ordering service system	QFD & TRIZ	A food ordering company in Taiwan
Tsung Ko (2017)	Modeling a hybrid design matrix for new product innovation	AD & TRIZ	Elderly Rehabilitation Equipment
Vinodh et al (2017)	Application of fuzzy quality function deployment for sustainable design of consumer electronics products	Fuzzy QFD	Auto parts
Song & Sakao (2017)	A customization-oriented framework for the design of a sustainable product/service system	AHP & TRIZ	M elevator company
Chowdhury & Quaddus (2016)	A Multi-phased QFD Based Optimization Approach to Sustainable Service Design	AHP & FQFD	health service in Bangladesh
Sabaghi et al. (2016)	Evaluation of products at the design phase for an efficient disassembly at the end-of-life stage	DOE&TOPSIS	Jet aircraft
Wu & Ho (2015)	Integration of green quality function deployment and fuzzy theory	Fuzzy Green-QFD	Mobile phone

Yu et al. (2015)	IncorporatingQFD with modularity design for improving product and its environmental compatibility at the end-of-life stage	QFDE &Modularity	Air-conditioning products
Younesi & Roghanian(2015)	A framework for sustainable product design: a hybrid fuzzy approach based on QFDE	Integrated QFDE	Transformer
Hosseinpour et al. (2015)	A benchmark-based method for sustainable product design	QFD & LCA	wheelchair
Borklu & Mayda (2014)	Development of an inventive conceptual design process, using systematic design of TRIZ and QFD	QFD & TRIZ	punching machine
Vinodh et al. (2014)	Integration of ECQFD, TRIZ, and AHP for inventive and sustainable product development	ECQFD, TRIZ‹AHP	automotive valves
Bereketli & Genevois (2013)	An integrated QFDE approach for identifying improvement strategies	Multi-aspect QFDE	hand blender
Kim & Yoon (2012)	Developing a process of concept generation for new product service systems	QFD & TRIZ	car sharing service
Yeh et al. (2011)	Integration of four-phase QFD and TRIZ in product R&D	QFD & TRIZ	notebook
Wang et al. (2010)	ECQFD & LCA based methodology for sustainable product design	ECQFD&LCA	electronics switch

Finally, by evaluating the product life cycle, the performance of this diaper was compared with the previous types. In this paper, they first tried to identify customer needs in general and in all aspects of the product using QFD and customer relationship and then using TRIZ, they tried to improve those improvable aspects of the product with the participation of experts in each section and through providing creative innovation. Therefore, the one-dimensional and scattered view of a product does not happen based on a specific specialty. Rather, it happens first by identifying the improvable points in the product and then engaging each specialty in its own respective section, in fact, a comprehensive look is taken at the design of Hygiene and health care products. Hence, it can be concluded that there are two points regarding the Inclusive Design of health products: 1- Systematic design, in a way that first the requirements and improvable points in the product are identified by means of management tools in design. Then, according to the customer's priorities and needs, the technical parameters are tested and examined by a specialist in that section. 2. Inclusive Design, in a way that vulnerable groups can be involved in the process of identifying needs.

3. Methodology

The integration of QFD and TRIZ methods makes it possible to effectively search for current market needs and the potential orientations of technological developments which lead to new products. The QFD matrix makes it possible to identify the most essential needs of users. Those needs have been evaluated in 30 seniors and their caregivers. The relationship between user needs and technical parameters was identified, ranked, and evaluated, and the principles of TRIZ's invention were used to resolve conflicts and create new concepts. QFD and TRIZ have complementary approaches and different time perspectives to search for market needs. While QFD identifies current needs, TRIZ identifies future needs through identifying patterns of technological evolution. Table 4 shows the increasing effect of QFD and TRIZ (Naveiri & Oliveira, 2018). In the following, the method of extracting and collecting data and the process of performing this work are described.

Table 4. -QFD/TRIZ synergy, *strong* ●, *medium* ○, *weak* △

Index	TRIZ	QFD
Customer satisfaction	△	●
Product quality	●	●
Profit	●	●
Market share	●	●
Innovation	●	○
Failure forecast	●	-
Support for intellectual capital	●	-
Technology perspective	●	-

3.1 Problem Statement

New challenges are emerging regarding the aging population. The product design professionals' Inclusive Design for social responsibility is new in relation to this challenge. Finding better ways for improving elderly people's relationships with their peers and their greater involvement in social activities increases their mental health and longevity. In this context, the problems of the elderly and the disabled, such as urinary incontinence, are one of the most common problems of old age that prevent the active participation of the elderly in social groups. Developing hygiene products for urinary incontinence and improving existing products can lead to the improvement of the elders' quality of life in their family relationships, social life, and work activities. Considering social factors in developing the products related to the elderly is of particular importance. However, research in the field of product design and development paid little attention to the social aspect.

The older adults' urinary incontinence problem is also problematic for their caregivers. Financial problems, as well as psychological and physical fatigue, are among the consequences for elderly caregivers. Given the above-mentioned problems, researchers believe that using high-quality products for urinary incontinence is effective in reducing the physical load for caregivers (Santini et al, 2016). Moreover, higher quality of urinary incontinence products, which reduces the presence of the caregiver, is very desirable for older adults, because in this way, their sense of dignity and self-esteem will be maintained more. This study is conducted with the aim of improving the current state of hygiene products in the country, by considering the needs of the target market, as well as the new or future technologies which can increase the products' quality.

3.2 Research Process

In the first step, the data about the needs of the product users will be collected through a semi-structured interview. There are several ways to identify customer needs. In this study, based on the research subject, a semi-structured interview will be used in an oral form. To do so, a series of default questions about the elderly problems with urinary incontinence products will be extracted from the literature and will be used as the basis of the interview. However, during the interview, the interviewees will be free to express their opinions and probably raise any number of new requirements. This type of interview is used in situations where the interviewee has special conditions or collecting information is observed during the interview process because complete information can't be obtained through standard questions. Data collection in such researches is collected using face-to-face semi-structured interviews (Santini et al, 2016).

The output of this section is the needs of the elderly in relation to adult diaper products, and 10 needs will be identified based on them. To rank the customer needs, a ranking questionnaire for customer needs will be used, and product experts will rank these 10 items by assigning a number from 1 to 10, according to their order of importance. Then the score of each need will be assigned based on the equation: "N (total number)-R(rank)". For example, rank 1 receives 9 points and rank 10 received 0 points. Figure 3 and Table 5 indicate the general characteristics of the interviewees regarding the customer needs and the product technical characteristics respectively. They determine the technical characteristics of the product:

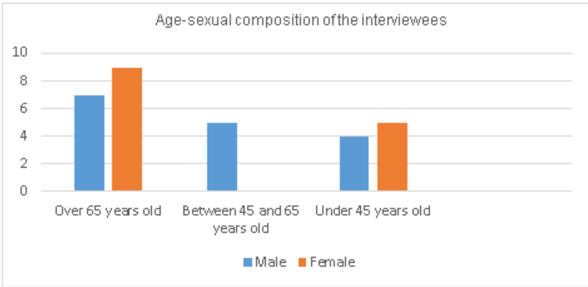

Figure3-General characteristics of the interviewees regarding the customer needs

Moreover, considering each customer need, one or more technical characteristics will be identified in the product by the product experts, and the output of this section is the product's technical characteristics. Specifying the characteristics makes it possible to identify the priority of each technical characteristic and its effect on meeting each of the needs in the QFD relationship matrix.

Table 5-General characteristics of the interviewees regarding the product technical characteristics

Connoisseur	Education	Job Title	Experience
1	Phd	Production Manager	14
2	Masters	Production Supervisor	12
3	Masters	Quality Control Manager	10
4	Masters	Production Planning Manager	8
5	Masters	Business unit expert	7
6	Bachelor	Technical expert of a production unit	4

Once the customer needs and technical characteristics of the product are identified, the QFD matrix will be formed, and the relationship matrix and the correlation matrix will be solved. At this stage, the QFD matrix will be formed according to the data related to customer needs and the product's technical characteristics. The output of this stage is the inventive ideas for resolving the identified contradictions which will ultimately lead to satisfying the needs that these contradictions arise from. At the ideation stage, the opinions of the design team will be considered and applied. The characteristics of the design team are shown in Table 6 (connoisseurs 1, 2, 3, and 4 in Tables 5 and 6 are the same).

Table 6-General Characteristics of the design team

Connoisseur	Education	Job Title	Experience
1	Phd	Production Manager	14
2	Masters	Production Supervisor	12
3	Masters	Quality Control Manager	10
4	Masters	Production Planning Manager	8
5	Masters	Nurse for the elderly	9
6	Bachelor	Nurse for the elderly	3

Finally, an evaluation will be performed according to the new concept of the product to determine whether the new concepts presented in relation to customer needs will improve the product. Innovative solutions will be represented as new technical characteristics and will be then integrated into a reference concept. At this stage, using the House of Quality relationship matrix, we will determine the impact that each of the technical characteristics (after implementing the ideas in the product) will have on customer needs (improves the need +, makes it worse -, or that need itself changes the product and formes a new idea =). If possible, we will once again generate new concepts for negative symbols through the use of TRIZ Contradiction Matrix, so that all relationships will be positive. Given the new concept of the product and through the re-evaluation of the relationship matrix, an initial evaluation of the new product will be performed. This matrix will examine the new product to check whether it has improved in meeting the customer needs (Clausing & Fey, 2004). The algorithm of the research stages is shown in Figure4.

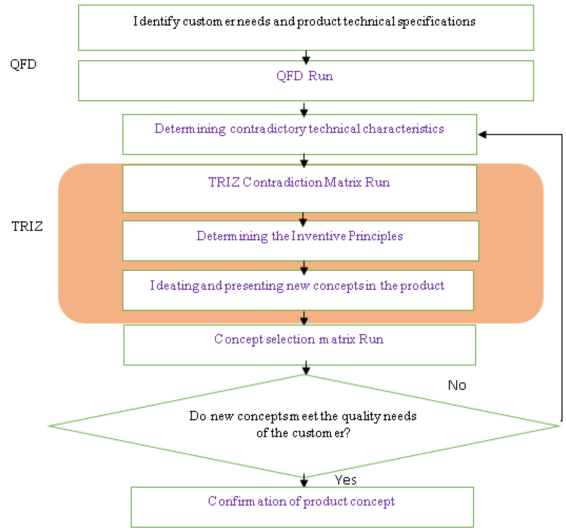

Fig. 4 Algorithm of the Research Implementation Stages

3.3 Steps of the Implementation Procedure (Case Study)

The steps for implementing the model and the input and output of each step are presented in table 7 to figure 10:

Step1. The user needs were identified through the interview with 19 seniors and 11 nurses of the older adults who could not be interviewed. Moreover, while considering each of the customer needs, one or more technical characteristics in the product were identified by product experts, and meeting the customer needs is related to these technical parameters.

Step2. The House of Quality matrix in this study consists of four main sections, including qualitative customer needs, technical and engineering requirements, relationship matrix, and finally technical correlations matrix. Its aim is to assess the type of relationship between a product's technical requirements and the identification of negative correlations between them. The effect of each technical characteristic on the needs of each

Table7-Customer Requirements

N	Customer needs	N	Customer needs
1	High absorption	6	Ease of changing
2	Not causing skin sensitivity	7	Elasticity of the side bands
3	Not spreading the bad smell	8	Not being visible and noticeable from the clothes top
4	Variety in size	9	Reasonable price of the diaper
5	Not causing skin rash and inflammation	10	Offering hygiene cleansing packs with diaper

user is shown through the use of assigned weight, which is one of the numbers (1, 3, and 9) that show the weak, medium, and strong relationships respectively. By the implementation of QFD in the first step, the ranking of the product's technical characteristics will be performed, which will take place in the House of Quality relationship matrix, by calculating the relative weight of each technical characteristic. In the roof section of the House of Quality and with the implementation of a correlation matrix, the contradictory technical characteristics will be identified, which will be the output of the QFD matrix for the implementation of TRIZ. The + and - symbols indicate the positive and negative interactions between the product's technical characteristics respectively. The negative interaction between the two characteristics indicates that either these two characteristics cannot simultaneously exist in the product or increasing the effect of one characteristic will weaken the other.

Table8-Technical Requirements

N	Product technical Characteristics	N	Product technical Characteristics
1	The material of the absorbent layer	7	Control of changing time for a diaper
2	absorbent powder type	8	Outer layer shape
3	Air exchange in the diaper's outer layer	9	Compatibility with body anatomy
4	fragrance materials	10	Glue material used between the diaper layers
5	Design of the accompanying hygiene package	11	Use of biodegradable materials as raw materials
6	The elasticity of the sidebands	12	Multiple diaper sizes
		13	Economic design

Step 3. According to the House of Quality correlation matrix and contradictory technical characteristics, at first an engineering parameter will be determined for each of the contradictory technical characteristics according to the Contradiction Matrix. Contradiction Matrix is a 39 x 39 matrix consisting of 39 engineering parameters. One parameter is in the vertical axis that needs to be improved and the other parameter is in the horizontal axis which should not be worse; and at the intersection of this matrix, there are the innovation principles of TRIZ that are used to solve this problem (Moehrle, 2005). The output of this step is the identification of the innovation principles corresponding to each pair of contradictory technical characteristics.

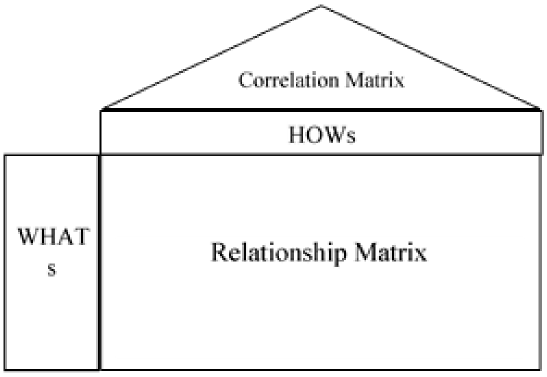

Figure 5-House of Quality (Naveiro & Oliveira, 2018)

Step4. Using the innovation principles obtained in the previous step, the design team will try to present inventive and operational ideas in the desired product, by using their own knowledge and experience. Ideation can be achieved as a team and by means of ideation methods such as brainstorming. Table 9 is a sample table:

	Improving feature / Worsening feature	Volume of moving object	Speed	Force	Tension or pressure	Shape	Reliability	Harmful actions due to the object	Easy to operate	Easy to repair	Complexity of device	Difficulties of detection and measure
		7	9	10	11	12	27	31	33	34	36	37
9	Volume of moving object	-	7,29,34	15,28,13,19	6,18,38,40	35,15,18,34	11,35,27,28	2,24,35,21	32,28,13,12	34,2,28,27	10,29,4,34	3,34,27,16
10	force	15,9,12,37	13,28,15,12	-	16,21,11	10,35,40,34	3,35,13,21	13,3,36,24	1,28,3,25	15,1,11	26,35,10,18	36,37,10,19
11	Tension or pressure	6,35,10	6,36,36	36,35,21	-	35,4,15,10	10,13,19,35	2,33,27,18	11	2	19,1,35	2,36,37
12	shape	14,4,15,22	35,15,34,18	35,10,37,40	34,15,10,14	-	10,40,16	35,1	32,15,26	2,13,1	16,29,1,28	15,13,19
15	Duration of action of moving object	10,2,19,30	3,35,5	19,2,16	19,3,27	14,26,28,25	11,2,13	21,39,16,22	12,27	29,10,27	10,4,29,15	19,29,39,35
33	Easy to operate	1,6,35,15	18,13,34	28,13,35	2,32,12	15,34,29,28	17,27,8,40	15,2,7	-	12,26,1,32	32,26,12,17	12,4,5

Figure 6-TRIZ Contradiction Matrix (Naveiro & Oliveira, 2018)

Table9 -The Idea Step

Contradictory technical characteristics	Corresponding engineering parameters	Innovation principles (Previous step output)	inventive solution (Output step 4)
X Y	✓ Efficiency ✓ power	**34**. Discarding and recovery **35**. Parameter changes	✓ changing the shape of the absorbent layer ✓ changing the type of materials

Step5. Finally, by implementing the concept selection matrix, it will be revealed which new concept will be accepted. At this stage, the concepts presented in the previous step are evaluated. The product concept is actually created by combining the solutions provided by the creative principles in the previous step. Due to the changes made conceptually and using creative principles in the product, the new product concept replaces the previous one. At this stage, any of the relationships identified in the first phase of the House of Quality (communication matrix) can be improved or weakened according to the new product concept. Relationships that improve in the new product concept receive a positive (+) sign; relationships that weaken receive a (-) sign, and relationships whose technical characteristics have been used to provide creative solutions receive a (=) sign. This means that these technical specifications have been used in the new product design. At this stage, if there is no negative relationship according to the product experts, the new product concept can be presented as a proposal. If there is a negative relationship, the previous TRIZ steps should be repeated by using the contradiction matrix and creative principles.

Table 10-Concept Selection Matrix

	Technical requirements			
customer's requirements	+	-	+	The concept of reference
	=	+	-	
	+	+	=	

3.3.1 Identification of Users' Needs

Given the number of needs identified through the interviews with older adults, customer needs are ranked from 1 to 10. Then a score is assigned to each rank (based on the total number of customer needs minus the rank assigned to each need). For example, 9 points is given to rank 1, and 0 points is given to rank 10. Finally, the relative weight of each elderly need was calculated by the sum of the points related to each need in relation to the total points. Table 11 displays the ranking of customer needs.

Table 11-The relative weight of customer needs

N	Customer needs	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Total points	Relative weight
1	High absorption	9	9	7	9	7	9	50	0.19
2	Not spreading the bad smell	5	6	4	4	5	6	30	0.11
3	Variety in size	2	0	1	2	2	1	8	0.03
4	Not causing skin sensitivity	7	8	8	7	8	7	45	0.17
5	Not causing skin rash and inflammation	8	7	9	8	9	8	49	0.18
6	Ease of change	6	5	2	6	6	5	30	0.11
7	Not causing discomfort on the top diaper tape	0	4	6	0	0	0	10	0.04
8	Being economical	4	2	3	5	4	4	22	0.08
9	Not being visible and noticeable from the clothes top	3	3	5	1	3	3	18	0.07
10	Hygiene package accompanying diaper	1	1	0	3	1	2	8	0.03
								270	1

3.3.2 Identification of Product's Technical Characteristics

After determining and providing the list of customer needs, the technical and engineering specifications related to each customer need (relationship matrix columns) will be determined by the engineers of Easy Life cellulose manufacturing plant.

Then, the relationship matrix questionnaire will be used to determine the level of performance and effectiveness of each technical need in respect of the customer needs. Experts in this questionnaire will score points as follows: 0 for lack of relationship, 1 for a poor relationship, 3 for a medium relationship, and 9 for a strong relationship. Once the relationship matrix is determined, the absolute and relative weight of technical characteristics will be obtained. If the relationship between each of the qualitative demands (i) and the technical characteristics (j) are defined by d_{ij}; and a_i is the degree of importance of each qualitative demand, i.e. the absolute weight of each technical characteristic will be obtained by the following relation:

(1-1) $$W_i = \sum a_i d_{ij} \; i = 1 \dots n \; j = 1 \dots n$$

The relative weight of each technical characteristic is also calculated through the following relation:

(1-2)
$$\text{relative weight} = \frac{\text{absolute weight of each characteristic}}{\text{Sum of the technical characteristics weights}} \times 100$$

3.3.3 QFD Matrix formation

Then, by using QFD, relationship matrix, and correlation matrix in House of Quality, the relationship between customer needs and technical requirements of the product, and the internal relationship between technical requirements of product with the opinion of cellulose industry engineers are also determined. The House of Quality relationship matrix and correlation matrix is shown in Table 11 and Figure 7, respectively.

Table12-House of Quality relationship matrix

Row	Relative Weight	Customer Importance	absorbent layer material	absorbent powder type	Air exchange in the diapers outer layer	fragance materials	Elasticity of the side bands	diaper changing time control	Economic design	Compatibility with body anatomy	Glue material used between the diaper layers	Shape of outer layer	Number of diaper sizes	Design of the hygiene pack accompanying diaper	Use of biodegradable materials as raw materials	Relative Weight
1	0.19	High absorption	9	9						1	1		3	3		0.19
2	0.11	not spreading bad smell	3	3	9	9						3				0.11
3	0.03	Variety in size					1			3			9			0.03
4	0.17	Not causing skin sensitivity	3	3	3	1		1	3	1	1				1	0.17
5	0.18	Not causing skin rash and inflammation	1	1	3		1	9						3	1	0.18
6	0.11	Ease of changing for elders					3			3						0.11
7	0.04	Not causing discomfort on the top diaper tape					3			3		9				0.04
8	0.08	Economic affordability					3		9				3	3	1	0.08
9	0.07	Not visible and noticeable from the clothes					3		3	9		9	3			0.07
10	0.03	Cleansing package accompanying diaper							3					9		0.03
	1	Technical absolute weight	2.68	2.68	2.04	1.17	1.10	1.80	1.52	1.49	0.35	1.27	1.27	1.61	0.43	19.41
		Relative weight	0.14	0.14	0.11	0.06	0.06	0.09	0.08	0.08	0.02	0.07	0.07	0.08	0.02	1
		Relative weight * 100	13.82	13.82	10.53	6.01	5.67	9.27	7.84	7.65	1.81	6.53	6.53	8.30	2.21	100

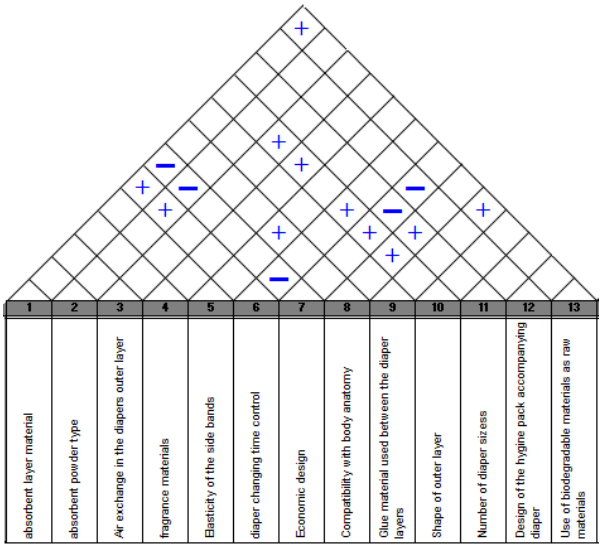

Figure7-House of quality correlation matrix

3.3.4 TRIZ as an Approach to Deal with Contradictions

The output of the correlation matrix, i.e. the technical characteristics which have negative correlations with each other, is entered as input in the Contradiction Matrix. At this stage, we first select the closest corresponding engineering parameter from the 39 TRIZ engineering parameters, found in the table for each of the contradictory technical characteristics. For example, the engineering parameter "Power" has been selected for the technical characteristics of "Absorbent Layers Material" and "Absorbent Powder Type", and the engineering parameter “Efficiency” has been selected for the technical characteristic of "Economic Design". Table 13 indicates the contradictory technical characteristics and the engineering parameters corresponding to each of these characteristics.

Table13-Correspondance of technical parameters with TRIZ engineering parameters

Product technical Characteristics	Corresponding engineering parameter	Product technical Characteristics	Corresponding engineering parameter
Improving the absorbent layers material, and absorbent powder type	✓ power	✓ ECO Design	✓ Efficiency
Controlling the time of changing diaper	✓ Accuracy of measurement	✓ ECO Design	✓ Efficiency
Design of the cleaning package accompanying product	✓ Ease of use	✓ ECO Design	✓ Efficiency

After determining the engineering parameters corresponding to each of the product's technical characteristics, the inventive principles associated with each pair of technical characteristics are identified at the intersection of the two parameters in the TRIZ Contradiction Matrix. The inventive principles in the Contradiction Matrix are located at the intersection of two engineering parameters, one of which is always known as the improving parameter and the other is known as the worsening parameter.

3.3.5 Presenting Inventive Ideas

At this stage of the TRIZ process, the project team must achieve a specific solution to the product's problem by means of creative principles. The technical contradiction solution must be in such a way that improvement in one of the product parameters does not lead to the weakening of other parameters.

Table 14-Identification of the inventive principles in the TRIZ Contradiction Matrix

Improving parameter	Weakening parameter
	Efficiency
Power	28 , 34 , 35
Accuracy of measurement	10 , 28 , 32 , 34
Ease of use	1 , 15 , 28

For instance, the technical contradiction between "power-efficiency" indicates that in order to improve the diaper's absorption power, a solution must be proposed that while improving the diaper's absorption power, the price of the product remains economical for the customer. The proposed solutions are of two types. the first group consists of solutions that do not have any negative effect on other parameters while improving one parameter. The second group consists of solutions that in addition to improving a parameter like product quality cause an increase in the product's price, but the customer is willing to pay the higher price for the higher quality and better service and it is affordable to the customer. The proposed ideas at this stage are shown in Table 15.

Table15-Presenting Inventive Ideas

Contradictory technical Characteristics		Contradictory parameters	Inventive principles	Inventive solutions
✓ Economic design	✓ Absorbent layer material ✓ Type of absorbent powder	✓ Efficiency ✓ Power	34. Discarding and recovering 35. Parameter changes or changing the physical states	Using perforated film in the inner layer of diaper Changing the type of materials used in the absorbent powder
✓ Economic design	✓ Diaper changing time	✓ Efficiency ✓ Precision	32. Color changes 28. Mechanics substitution	Using wetness indicator to show the time for changing a diaper Using a humidifier system in the diaper
✓ Economic design	✓ Hygiene pack accompanying the product	✓ Efficiency ✓ Ease of use	1. Segmentation	Designing a hygiene pack accompanying diaper including cleansing foam and pad being offered along with the main product
✓ Economic design	✓ Number of diaper sizes	✓ Efficiency ✓ Ease of use	1. Segmentation 15. Dynamics	Producing diapers with more variety of sizes than the three main sizes of small, medium, and large. Producing diapers suitable for people with extra-large sizes

3.3.6 Concept Selection Matrix

At this stage, the product concept which was created in the previous step is called "reference concept". By considering the reference concept and reviewing the relationship matrix, an attempt is taken to identify the improved or weakened relationships. In this study, the reference concept based on which the relationship matrix must be formed is an adult diaper with a double-layered absorbent core and perforated film structure. The absorbent powder used in this diaper is paper pulp-free and is only based on super absorbent powder, and a wetness indicator or moisture sensor for alerting the diaper changing time has been added to this product. It also has extra-large sizes and customers can order hygiene accessories along with the diaper. At this stage, any of the relationships identified in the first stage of the House of Quality (relationship matrix) can be improved or weakened based on the new product concept. The concept selection matrix is shown in Table 16.

Table16-Concept selection matrix

Customer needs \ Technical Characteristics of product	absorbent layer material	absorbent powder type	Air exchange in the diapers outer layer	fragrance materials	Elasticity of the side bands	diaper changing time control	Economic design	Compatibility with body anatomy	Glue material used between the diaper layers	Shape of outer layer	Number of diaper sizess	Design of the hygiene pack accompanying diaper	Use of biodegradable materials as raw materials
High absorption	=	=						+	+		+		
not spreading bad smell	+	+	+	+		+				+			
Variety in size					+			+			=		
Not causing skin sensitivity	+	+	+	+		+		+	+			+	+
Not causing skin rash and inflammation	+	+	+		+	=							+
Ease of changing for elders					+			+			+		
Not causing discomfort on the top diaper tape					+			+		+	+		
Economic affordability						-	-					+	
Not being visible and noticeable from the clothes top					+	-	+	+		-	+		
Cleansing pad accompanying diaper							+					=	

The new product concept shows that the product design has been weakened at this stage in terms of changes in “the shape of the outer layer” and "economic affordability". The shape of the outer layer has changed due to the concept of wetness indicator in the outer layer of the diaper showing the time for changing the diaper. Moreover, using a diaper moisture sensor that alerts the caregivers to the time of changing the diaper by changing color or an alarm is not suitable for the elderly. The changing time alert by creating vibration in the diaper is also not applicable for most older adults needing a nurse or a caregiver. Therefore, the humidity sensor must be able to warn the caregiver, while those around the elderly do not notice this warning. It should also be economically affordable for the customer.

The contradiction that exists at this stage stems from an improving characteristic that is called "diaper changing time control" and two weakening technical characteristics that are "diaper’s shape of outer layer "and "economic design". At this stage, the engineering parameter corresponding to the "diaper changing time control" that we intend to improve is selected to be "automation level". On the other hand, the weakened parameters are “diaper’s shape of outer layer" and "economic design". The parameters corresponding to these two characteristics are "device complexity" and "efficiency" respectively. "Automation level" is selected because the alarm sensor must be more advanced than a simple wetness indicator used in child diapers. Increasing the product’s "automation level" will lead to an increase in the "device complexity", which is a negative characteristic, and this means that to solve this technical contradiction, while increasing the level of automation, more complexity in the diaper’s outer layer must be prevented. Therefore, the project team must provide a solution that while meeting the need for "having strict control over the diaper’s changing time", does not complicate the shape of diaper’s appearance and be economically justifiable for the consumer.

Table17-Correspondance of technical parameters with TRIZ engineering parameters

product technical characteristics	Corresponding engineering parameter	product technical characteristics	Corresponding engineering parameter
Diaper’s changing time control	Automatic level	The shape of the outer layer Economic design	Device complexity Efficiency

The inventive principles associated with the parameters of "automation level", "device complexity" and "efficiency" are identified in the Contradiction Matrix according to Table 18.

Table 18-TRIZ Inventive Principles

Improving parameter	Weakening parameter	
	Efficiency	Device complexity
Automation level	5,12,26,35	10,15,24

In the following, the project team presented their ideas according to the inventive principles.

Table19-Inventive Ideas

Contradictory technical Characteristics		Contradictory parameters		Inventive principles	Inventive solution
The diaper’s changing time control	The shape of the outer layer	Device complexity	Automation level	15. dynamics 24. intermediary	Using a humidifier that has the ability to send messages on mobile software.
The diaper’s changing time control	Economic design	Efficiency	Automation level	5. Merging 26. Copying	Using a humidifier device that can be removed and reinstalled.

4. Findings

This study aimed at identifying and ranking the needs of older adults in using urinary incontinence products and improving the conceptual design of the desired product (adult diaper) by using Quality Function Deployment (QFD) and systematic innovation. By using Quality Function Deployment, needs of the elderly concerning adult diapers were identified and prioritized, and then, by using the opinions of product experts, the technical characteristics related to the needs of the elderly were identified and prioritized. By using systematic innovation methods and product expert opinions, practical ideas for improving the design of the future product were conceptually presented.

Table20-Accepted product concepts

New technical characteristics	New product concepts
1	Using a replaceable absorbent pad attached to the diaper
2	Increasing the absorbing power of diapers by using perforated film and super absorbent powders (removing the paper pulp)
3	Designing a complete hygiene package including a diaper and other necessary hygiene products with the possibility for the customers to select from different hygiene products when ordering
4	Providing diapers in extra-large sizes for specific people and as a customized product
5	Designing a reusable sensor to inform about the diaper changing time

4.1. New Accepted Product Concepts

Each new product concept creates changes in the social or economic functions of the product as described below:

Adding a replaceable absorbent pad to the diaper: Mild urinary incontinence in old adults causes the excretion of small amounts of urine which causes discomfort and the need to change the diaper. On the other hand, repetition of urinary excretion in small amounts occurs immediately after a few minutes and too much repetition very soon requires changing diapers one after another, so the cost will be very high. Nurses usually set a fixed time to change the diaper (for example, once every three hours in a nursing home), and this sometimes causes the defecation to take place a short time after the previous change. Waiting for subsequent diaper changing times can cause problems such as urinary tract infections and diaper rashes caused by urine. There are two important issues regarding mild urinary incontinence and recurrent incontinence. First, the precise control of time for changing diapers, and second, in case of mild incontinence, the diaper should not be completely changed. Cases 1 and 5 help with meeting this need.

1. **Super absorbent powders:** In the product under study, the absorbent powder is made by a combination of paper pulp and super absorbent material. Using super absorbent materials and removing the paper pulp would be better economically and environmentally, and also for the function of the absorbent layer.
2. **The possibility of ordering a hygiene pack along with the diaper:** Using hygiene products for personal cleaning is necessary for people with urinary incontinence. Some seniors who live in their own homes, and even elderly caregivers in nursing homes, have a problem and face difficulty in providing a complete package of diapers and accompanying hygiene products, and they can't order the supplies they need or different combinations of them together in one try. Creating this opportunity for the elderly can be very rewarding. The hygiene package accompanying the diaper can include a set of hygiene products needed by the elderly that can be ordered by the customer, including products such as sanitary pads for cleaning the body, hygiene cleansing foam, diaper bag, etc. Providing this opportunity is a type of service that will be created through the company's marketing website.
3. **Extra-large size:** Usually the older adults and the people with disability, or those who are hospitalized in the long run, become overweight and compared to their peers, have more problems with urinary incontinence. Customized production of special sizes of diapers for these people, while meeting this customer need, will also be economically justified for the manufacturer.
4. **Biosensors:** Usually the cost of urinary incontinence includes the costs of caregiving and buying the diaper, hiring a nurse, and medical expenses. Urinary tract infections, as the most common bacterial infection, need significant health care. Moreover, skin rashes and dermatitis, and diseases caused by not changing the diaper in a timely manner are some instances of urinary incontinence medical and health problems. In addition, urinary incontinence reduces the independence of old people and causes limitations for the elderly's social life which will negatively affect their quality of life. The problem of urinary incontinence makes them feel embarrassed and lose their self-esteem. The incontinence diaper with sensors that can tell the exact time for changing the diaper increases the caregiving

quality and it is also very desirable for maintaining the dignity of the elderly because it reduces the presence of a third party and also reduces the caregivers' repeated checkings on the diaper. Also, the fact that these sensors are not disposable will have an economic justification for the manufacturer and will not increase the price of the product for the consumer.

4.2. Suggestions for Further (Applied) Research

It is suggested that the research and development unit of Easy Life Company should produce the prototype of this diaper following a process of a feasibility study and cost-benefit estimation and if successful, it should start the mass-production of the new product.

4.3. Directions for Further Research

For future research, it is suggested other idea generation methods should be used to develop the product concept. Moreover, the use of value engineering technique and function analysis and its combination with the article model can help to make the design tools more systematic and comprehensive.

5. Conclusion

Given the demographic issues and the growing trend in population aging in the world and in our country, the elderly problems and issues have become more important today. As we move forward, issues related to the young population of the society, such as unemployment, marriage, etc., are replaced by issues related to the elderly population, such as retirement, different types of insurance, hygiene care for the elderly, and so on. Inclusive Design, through considering the product's specific functions, with regard to the needs of vulnerable groups such as the elderly and the disabled leads to a comprehensive design at the initial stage of design and it assures the manufacturer that the product is flexible enough to be used in all consumer groups. In this study, the TRIZ Contradiction Matrix was used for innovation and the generation of ideas, and the QFD method was used for information and data analysis. Using these two instruments can be helpful in generating new concepts in designing useful products, because through QFD method, first of all, we can identify the product technical characteristics which are related to customer needs, then we can focus on the most important ones, and purposefully avoid wasting time and money in the project process. Second, using TRIZ and the tools including Contradiction Matrix and the forty principles of the invention provides a mental framework for participants in the ideation phase to benefit from the experiences of the previous inventions.

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Process Mining: Basic Definitions and Concepts

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Abstract

Business Process Improvement (BPI) paradigm can be implemented on recorded data of real process execution. This is done by analyzing this information and come up with real insights to BP improvement. Even if such model is not available, the presence of a log of activities is very frequent. So, the key idea is that a log can exist even if no process model is present. The spread way of existing BPI methodologies put forward the complexity of their achievement the BP improvement goal. Moreover, they could be driven by many factors. Nonetheless, the common goal is to speed up generating an improved BP.

A recent trending improvement BP method is process mining, compared with existing BPI methodologies, Process Mining had more computer capabilities to implement BP improvements results. However, there are several ambiguities in understanding their general context that must be defined. In this paper, we present basic definitions and notations related to process mining discipline.

Keywords: Process mining, Business process improvement, discovery, conformity, enhancement.

1. Introduction

For some years, the usage of information systems has been rapidly growing in companies of all kinds and sizes. New systems are moving from supporting single functionalities towards a Business Process Management (BPM) orientation (Van der Aalst, 2016; Lamghari et al., 2019).

In this context, activities that companies are required to perform, to complete their own business, are becoming more complex and require the interaction of several persons and heterogeneous systems. A possible approach, to simplify the management of the business, is based on the division of operations in smaller "entities" and on the definition of the required interactions among them.

The term "Business Process" (BP) refers to this set of activities and interactions. As example, we cite the process of handling of a loan application (service), the process of emergency (healthcare), the process of car manufacturing (production), etc. Indeed, several tasks or activities are executed in one instance of such a process. A process instance is commonly denoted as a case, i.e., the activities of the process that operate on the case. Each case of a process has a defined start point and end point.

The seminal articles on business re-engineering (Hammer and Champy, 1993) and (Davenport, 1993) have established the focus on the processes of an organization in management practice. Furthermore, organizations should radically reorganize their work along their value-adding processes. A large body of work, both from industry and from academia, has been organized around the belief that performant processes are the foundation of any successful organization. The basic problem that is being tackled is: How do organizations define and execute performant processes?

This problem has been addressed from various viewpoints and with several approaches. For example, management trends and strategies such as Business Process re-engineering (Elapatha et al., 2020), Lean management (Saxby et al., 2020), Six sigma (Thomas et al., 2009), research fields and methods such as workflow management, and adaptive case management. Moreover, many software systems for BP execution tools have been proposed. For example, Staffware, COSA, YAWL, Bizagi, Bonita, Camunda, jBPM, IBM Business Process Manager, Oracle BPM Suite, etc.

Beyond, BPM can be seen as the umbrella-term that encompasses all those methods that are concerned with the design, enactment, monitoring, and optimization of processes. The main objective of BPM is to align the process with the objectives of the organization. In this sense, each process must be configured, so that the results of the process lead to the achievement of the business goals.

The BPM approach tends to provide more support for various forms of analysis (e.g., simulation) and management support (e.g., monitoring). In many cases, analysts are interested in a real system behaviour, which may be hidden from domain experts and system engineers. To this purpose, most of the software that is used to define and to help companies in executing such processes, typically, leaves a trace of the executable activities. These traces called (Event log). Log consists of the name of the activity and the time the activity is executed; moreover, it is important to note that the traces are grouped in "instances" (can emerged a set of "cases"). Typically, it is necessary to handle several orders at the same time, and therefore the process is required to be concurrently instantiated several times. These instances are identified by a "case identifier" (or "instance id"), which is another field typically included in the log of the traces. Sometimes, especially small, and medium companies do not perform their work according to a formal and explicit BP; instead, they execute their activities with respect to an implicit sorting. Even if such model is not available, the presence of a log of activities is very frequent. So, the key idea is that a log can exist even if no process model is present.

The Business Process Improvement (BPI) paradigm can be implemented on recorded data of real process execution (traces). This is done by analysing this information and come up with real insights to BP improvement. The spread way of existing BPI methodologies put forward the complexity of their achievement the BP improvement goal. Moreover, they could be driven by many factors. Nonetheless, the common goal is to speed up generating an improved BP. In this context, the most trending business process improvement method is PM (Van der Aalst, 2016). However, there are several ambiguities in understanding their general context that must be defined. Therefore, our paper is organized as follows: Section 2 presents existing methodologies related to business process improvement. Section 3 gives a general introduction to the Process Mining field, starting from the PM definition. Section 2 continues with illustrating PM categories and defining the very basic notion of event logs. Section 3 discusses different process models representations. Moreover, a list of process mining algorithms and tools are given (Section 4). The paper finishes with a comparative study between traditional BPIs methodologies and the process mining methodology, showing process mining advantages (Section 5).

2. Process Mining

PM (Van der Aalst, 2016) is a relatively new field incorporating techniques for the discovery, monitoring, and enhancement of real processes by extracting knowledge from the information system event logs. Indeed, PM bridges two different fields: Process Science and Data Science (see Fig. 1). Process Science is a broad area of process modelling, analysis, and optimization. It incorporates Stochastics (analysis of random processes, using Markov chains, queuing networks, and simulation), Optimization (finding the best possible process implementation by applying mathematical optimization techniques), Operations Management & Research (designing and controlling production processes from management and mathematical modelling perspectives), Business Process Management (methods and techniques for the modelling, execution, and enhancement of processes). Business Process Improvement (Six Sigma techniques and Business Process Re-engineering), Process Automation & Workflow Management (tools and methods for the processes execution, including routing and resource allocation), Formal Methods & Concurrency Theory (analysis of process behaviors, using Petri nets, finite state machines, and other formal models). Data Science incorporates all aspects of data analysis and includes Statistics, Algorithms (providing efficient data processing), Data Mining (methods revealing unsuspected relationships in data sets), Machine Learning (techniques for giving computers capability to learn without being explicitly programmed), Predictive Analysis (methods predicting the future trends), Databases (techniques for storing data), Distributed Systems (infrastructure for data analysis), Visualization & Visual Analytics, Business Models & Marketing (techniques for turning data into real value), Behavioural/Social Science (methods for the analysis of human behaviour), Privacy, Security, Law & Ethics (principles protecting individuals from "bad" data science practices).

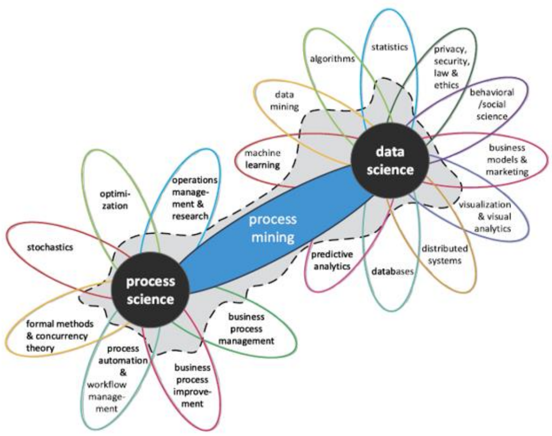

Fig. 1. Overview of process mining and its three types of techniques

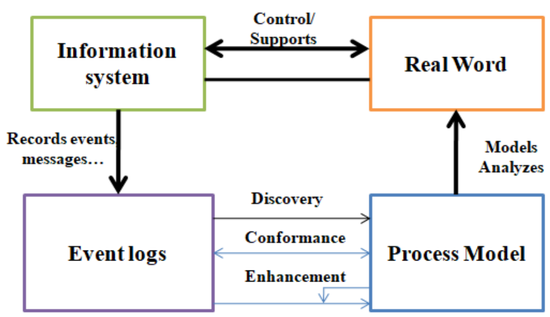

Fig. 2. Overview of process mining and its three types of techniques

2.1 Categories

PM (see Fig. 1) is defined by three categories (Van der Aalst et al., 2011): (1) process discovery, (2) conformance checking, and (3) enhancement.

(1) Process discovery is a challenging task for many reasons. Often event logs are incomplete, i.e., only a fraction of possible behaviors is observed. The other issue is that it can be difficult to uncover the composition of choices, iterations, or parallel executions, represented in the form of a flat event log. It describes process mining only in the offline setting, i.e., only finished process cases are analysed. Generally, process mining is not limited to the offline setting. It also entails methods such as prediction and recommendation based on current process data in an online setting. In the scope of this thesis, we consider the offline and the online setting. The challenge here is the demand of high-quality data and the structured form of resulted processes.

(2) Conformance checking methods find deviations from the expected behaviour. The expected behaviour can be represented in the form of a process model or an event log. One of the main challenges is the computational complexity. Typically, complicated process models and event logs lead to an exponential growth of possible alignments. The other challenge is to provide an intuitive visualization of alignments, helping analysts to reveal important discrepancies. Beyond activity names and timestamps, an event log may contain additional information, such as performers, costs, IP addresses, or other domain specific data.

(3) Enhancement techniques enrich process models with this information. Besides additional attributes taken from the event logs, these could also be results of conformance checking or performance analysis techniques. Model enhancement also considers an event log and a process model as inputs. This means, it is possible to improve an existing process model by looking in the past. Common aspects in model enhancement are time and cost. After discovering a process model from an event log, the discovered process model can be used to analyse for performance indicators, for example average throughput time and costs for improving or re–engineering the process. The bottleneck problem can be identified by analyzing waiting times between activities. After identifying the cause of bottlenecks, the process model can be enhanced at the right places. Enhancing resource performance is one important aspect. A social network in a workplace can be constructed by process discovery. It can give an idea of work collaborations and balance workload to improve resource performance. There is no restricting procedure how a process model can be enhanced. It depends on what problems an organization discovers and how an organisation wants to improve.

2.2 Event Logs

The PM typically assumes that BP execution data are stored as event logs. An event can be considered as the starting point of process mining. The event log structure consists of cases or completed process instances. Each case is made of a sequence of events, called a trace. An event can have any kind of additional attributes (timestamps, cost, resource, etc.) depending on the organization purposes. These additional attributes are important for monitoring the BP improvement. For example, bottlenecks cause that can slow-down the process flow. The event logs notation may depend on the information system treatment or purposes. However, the important point is the quality of these events that can heavily affect the process model representation and by necessity the main business of the organization. Therefore, event logs should be treated as first-class.

a. Notations 1 (Event, Trace and sequence or case): From a mathematical standpoint, each event in an event log is assigned to an activity executed for a singular process instance (one trace). For each trace, all events belonging to that case are ordered in a chronological style (see Figure 2.3.1). In this regard, A = {a1, a2, . . . , an} denotes a finite set, where ai, i:1, 2, ….,n is an activity of a case or sequence of length n. Thus, one case l can be expressed as l=<a1, a2, . . . , an > and < > denotes an empty sequence. The event logs L with n cases and r repetitions can be expressed as $L = [l_1^r, l_2^r, \ldots, l_n^r]$. For instance, the event logs L=[< a, b, c, d>20 , <a, c, b, d>15] signifies l1 =< a, b, c, d> repeated 20 times, l2 =<a,c,b,d> repeated 15 times, etc.

b. Notations 2 (Noise, Infrequent, incomplete, and chaotic): In a real-life setting, without a-priori knowledge on the process, it is difficult to distinguish between data quality problem: What is considered undesirable behavior depends on the application setting? When looking at the mainstream behavior of the process? then, all infrequent behavior is undesirable. When looking for workaround and divergent process executions, where some infrequent behavior may be desirable.

To explore these deficiencies, we use the following notations: $L = [l_1^r, l_2^r, \ldots, l_n^r]$ is the event logs, where its composite sequences can be denoted as $l_0, l_1, \ldots, l_n$ and one sequence or case is expressed as

$$l = \langle a_1, \ldots, a_n \rangle.$$

1. Noise: entail outliers that were recorded due to errors (Incorrectly logged).
2. $A = \{ a_1 / a_1 \neq a_i, \quad i = 2, \ldots, n \}$. This point describes events of activities that were executed out of the normal order.
3. Infrequent: low-frequent behaviour. For instance, events recorded due to temporary workarounds, and they are correctly logged. $L = \{min_{l \in L}$ where $min_{l \in L} \neq max_{l \in L}\}$
4. Incompleteness: Partial traces. In this paper we mean by incompleteness the problem of missing events. For instance, $U = \{\langle\rangle / \exists\, i = 1, \ldots, n, \quad a_i \in l\}$. To do so, traces are not complete in term of execution, i.e., events must be executed in the normal process but are not observed in the recorded traces).
5. Chaotic activity: can happen anywhere in the process Ch={a_1, a_2, . . . , an / i= 1,…,n }. For example: L=[<a, b, c, d, C_h>,<a, b, c, C_h , d>,< a, b, C_h , c, d>,< a, C_h , b, c, d>,< C_h , a, b, c, d>]. C_h takes any position from a1 to an. Ch is a chaotic activity. We will learn how to filter chaotic activities in the following sections.

3. Process Models

Process models (see Figure 3) are used to visualize, describe, prescribe, and explain the behaviour of processes of an organization for a wide range of objectives such as: communication among stakeholders, process improvement, process management, process automation, and process execution support. Concrete examples are the comparison of the "as-is" and the "to-be" process, documentation for complying with regulatory requirements such as ISO 9001, and the analysis of performance related problems such as bottlenecks and inefficiencies. Depending on the goal of the event logs analysis and on the analyst's personal taste, several ways of process visualization can be used. The most common are Petri Net, Transition Systems, Petri Net and Business Process Management Notation (BPMN).

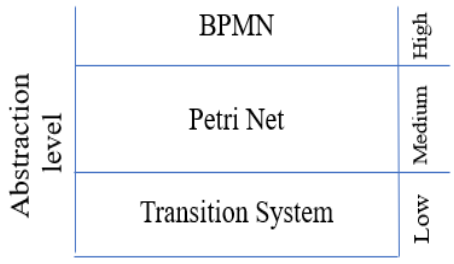

Fig. 3 Process Modelling Notation

The main benefits of adopting a clear business model, through different levels of abstraction, are summarized in the following two points:

(1) It is possible to increase the visibility of the activities, that allows the identification of problems (e.g., bottlenecks) and areas of potential optimization and improvement.
(2) Grouping the activities in "department" and grouping the persons in "roles", in order to better define duties, auditing and assessment activities.

These workflow languages aim at constructing a well-defined and highly automated BP. As a result, processes become more structured. Structured process is referred to rigorously defined process, less complex and with high repetition frequency. The definition of a structured process as given by Devonport is as follows: Structured Process/Lasagna (see part a of Figure 4) is defined as a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action (Augusto et al.,2018). Therefore, structured processes comprehend those processes whose activities execution consistently follows a predefined process model reference (Werner and Gehrke, 2013). Since a formal representation of these processes can be easily described prior to their execution, tightly framed processes are characterized as fully predictable and repetitive and after their design-time description, they can be repeatedly instantiated at runtime. Examples of this category are production and administrative processes and as well as bank transactions that are executed in an exact sequence to comply with legal norms.

Unstructured process/spaghetti: every instance of the process can be different from another based on the environment, the content and the skills of the people involved. These are always human processes. These processes may have a framework or guideline driving the process but only as a recommendation (Bukhsh et al., 2017). Therefore, unstructured process (see part b of Figure 4) is partially or totally not predefined, adaptable, content–driven and knowledge worker involved. We can then define their characteristics as follows:

- Diversity: processes that can generate a set of execution cases that are structured very differently.
- Knowledge–Intensive: Decisions in an unstructured process that are based on a lot of information, which may be provided from different resources.
- Uncertainty: There is no single answer or end–result in an unstructured process.
- Flexibility: There is no single way to complete an unstructured process. Each next step depends on the previous one and could be completely different every time we run the process.

Moreover, figure 4 illustrates the transformation of a spaghetti process to become more comprehensible as a simplified process model. The operation simplifies process models by keeping high frequent behaviors and filtering out low frequent behaviors. Indeed, executing loosely structured processes generates unstructured behaviors (Taylor, 2014). After mining an unstructured log, a spaghetti-like process can be revealed. "Spaghetti processes" is a metaphor of unstructured ones.

It cannot be assumed that a spaghetti–like process is wrong or that it has a problem caused by process discovery algorithms. It rather means a process model accurately reflects reality. However, spaghetti processes still have issues that are difficult to be analyzed and hard to understand due to its complexity. In this context, it is a very interesting challenge to simplify an unstructured process into a more structured one. The BP characteristics (see Figure 5) can help to determine the system within we will implement our business processes. These systems can be defined as systems with intensive data or with intensive knowledge (see Figure 5). Here, we illustrate the passage between data–intensive system and knowledge–intensive system. Obviously, unstructured processes are composed of a set of structured processes. Indeed, process mining concept consists of treating well-structured processes. For this reason, PM still meaningfully usable for unstructured processes. Consequently, PM can support system with intensive knowledge, like Enterprise Content Management (ECM) and Adaptive Case Management (ACM) system, and systems with intensive data like BPM.

In (Hammer and Champy, 1993; Webber, 2011), the authors focus on how redesigning BPs by presenting four dimensions to quantitatively measure process performance (time, cost, quality and flexibility). This method cannot treat the three first phases (Design, Model, Execute) of the BPM life cycle because it is used after the execution phase. Further, the work in (Davenport, 1993) defines improvement metrics only in the monitor phase by controlling data related to the BP objective. Then, as stated in (Elapatha et al., 2020), the authors present a scientific method to evaluate BPM products by defining a set of criteria for each BPM phase except the optimization phase. Also, as reported in (Saxby et al., 2020) the author focuses on the objectives of performing BPM design. As well as cited in (Thomas et al., 2009), the authors identify the new functional requirements for a Semantic Business Process Management (SBPM) System for each phase of the BPM life cycle and explain the benefits of adopting semantic technologies in SBPM. The authors specify requirements, rather than solutions and metrics. Thus, in (Baluch et al., 2012) the authors propose a method to evaluate and monitor the business process against performance requirements and show the effects of ongoing processes on business goals, in a real-time manner. Additionally, the paper of (Harry, 1998) treats only the implementation phase of the BPM lifecycle. Furthermore, the authors in (De jong et al., 2016) use data warehouse in the BPM life cycle in order to support the tree following phases (Execute, Monitor, Optimize). Last, the work in (Kanji, 1990) considers the whole BPM life cycle by implementing techniques for process mining and intelligent (re)design to support the redesign and diagnosis phases and thus close the BPM life cycle.

4. Process Models

In this section, we resume existing process mining algorithms and tools

4.1 Algorithms

At the heart of a PM discovery technique lays process mining algorithms. These algorithms, often embedded in the process mining software, translate the data from event logs into readable models. Several algorithms are available, each having its own properties concerning the form of input, conversion of data, and form of output. One must pick the right algorithm for a dataset for the right goal and right way of visualization. Much has been written about the mining algorithms. Thus, a process discovery algorithm constructs a generic process model based on event logs. It is an abstracted and general representation of real event logs. Several discovery algorithms are described with basic representation of process models, like alpha algorithm. Other algorithms are representing different levels of abstraction combined with clustering and classification techniques, to model processes from unstructured and complex events. In this regard, we are inspired by (Van der Aalst et al., 2018) to list the following process discovery algorithms:

The first miner developed is the Alpha–algorithm (Sang, 1991). This algorithm is based on eight simple mathematical definitions and visualizes its models in the Petri Net modelling language. Because of its simplicity, it is popular among scholars, but it is unpractical in real-life, because of its difficulty in handling noise, infrequent/incomplete behavior, and complex routing constructs. A second miner is the Heuristic miner (previously called Little Thumb), is better equipped to handle complex routing and it can abstract exceptional behavior and noise, making it suitable for actual logs (Vanden Broucke and Weerdt, 2017). The third algorithm is Fuzzy miner that focusses on unstructured behavior and large event logs. Its output is configurable to reach a desired level of abstraction but can only be visualized in a fuzzy model (Gunther and Van der Aalst, 2007). Fuzzy mining adaptive process simplification based on multi perspective metrics in the international conference on business process management. Springer, Berlin, Heidelberg). Indeed, it deals with process complexity. It highlights significant information and hides less significant activities. In this sense, fuzzy miner simplifies unstructured processes.

The simplification process aims at preserving significant behavior, while less significant but highly correlated behaviors are aggregated into clusters, and less significant or less correlated behaviors are abstracted. Other interesting algorithms are:

(1) Inductive Miner (IM): treats events by grouping them into sub-logs. For each sub–logs, a sub-process is generated. Then, a combination between the resulted sub-processes are released to obtain the generic process model. In this respect, the IM algorithm produces sound models (Bogarin et al., 2018), i.e., less none-conformities detected, and it fits with the majority of present logs. Besides, it cannot identify complex and non-local process control patterns.
(2) Genetic Miner (GM): randomly creates process models from logs. For each process, the precision metric is calculated. Then, sound models are combined based on the mutation operation. The genetic algorithm improves models according to specific objective. The main limitation of this approach is their complexity in discovering and representing process models from real data sets (Vanden Broucke and Weerdt, 2017). State Based Regions (SBR): generates a Petri net from a Transitions System (ST) based on specific abstractions, such as: Set, Multi-Set, Sequence, and other types of abstractions, in which each state of the ST can be represented by a complete or partial trace. This algorithm ensures the fitness metric, as well as the identification of complex control structures. On the other hand, SBR is unable to process incomplete and noisy logs (Van der Werf et al., 2008).
(3) Language Based Regions (LBR): The main idea of this algorithm is to find places based on the language process. All candidate places correspond to a language region. The discovered Petri net will be obtained by adding a place for each positive solution based on linear resolution. Each solution is represented as a triplet (A; B; C), where A is the set of inputs arcs, B is the set of outputs arcs and C is the number of tokens in the square. Indeed, the LBR algorithm uses properties derived from logs (causal relationships), to determine the final model by describing different places. Unfortunately, this algorithm is unable to process incomplete and noisy logs (Van der Aalst et al., 2018).

4.2 Tools

Currently, there is a wide range of research and commercial tools available in PM area: ProM1, Disco2, ARIS Process Performance Manager3, QPR Process Mining4, ProcessGold5, Celonis6, Minit7, and myInvenio8. Indeed, several process mining tools are available. Choice can be based on a specific needed set of functionalities, supported data formats, but also costs. Finding the right tool can be difficult since no comprehensive comparison exists.

Table 1 shows a list of process mining tools. Overall, three earnings models can be distinguished. First the common licencing structure where an organization can buy the tool for a certain period or indefinitely. The tool can be sold in combination with or without support for implementation or analysis. This is the case with, for example, ARIS BPM (Process Performance Manager), Celonis Process Mining, and Disco. Another earnings model is offering process mining as a service (PMaaS). This is provided by Icris and Coney. And lastly, several open-source tools are available. Most famous example is ProM, but also Apromore is popular. Based on the number of academic publications on the topic, open-source process mining platform ProM seems to be the most popular. ProM is an extensible framework that runs on Java and obtains its functionality by a wide variety of plug-ins. Because it is an independent platform and is developed by process mining "creator" Will van der Aalst, it is popular among scholars performing applied research. There are over 1500 free plug-ins available, each with different functionalities and options (Van der Aalst, 2016). For example, the use of different miners (heuristic, alpha-algorithm, and fuzzy), sorts of output (Petri Net and BPMN), and types of analysis (process discovery, dotted chart, and social networks). However, the academic character makes it difficult to use. Manuals and instructions are missing, and support can only be found in its community of volunteers. It seems that only few commercial organizations use this tool and even if they do so, they mostly use it to learn the concept of process

[1] http://www.promtools.org/doku.php

[2] https://fluxicon.com/disco/
[3] http://www2.softwareag.com/
[4] https://www.qpr.com/solutions/process-mining
[5] http://www.processgold.com/en
[6] https://celonis.com/
[7] https://www.minit.io/
[8] https://www.my-invenio.com/process-mining-vision/

mining before buying more user-friendly tool.

A more user-friendly process mining tool package is Disco, Developed by Fluxicon. Disco lacks some functionalities when compared to ProM, but distinguishes itself with a fast, well documented, and clear interface. Very limited knowledge on process mining is required to perform an analysis. But the lack of real-time connections to databases makes it less useful for large companies. It seems logical that Fluxicon focusses on small and medium-sized enterprises.

A third tool package, used by MoD, is ARIS Process Performance Manager. This package contains three components: the administrator's section, the business analyst's section, and the dashboard.

The section for the administrator is used to load the data. This can be a single file, but also a connection to a database. A good example is SAP. With the right connector, the SAP databases can be periodically and automatically loaded into the ARIS databases. Initializing this connector will cost some effort but can be a good investment. The business analyst's section of the tool is used for in-depth analysis. With the use of filters, selections of the dataset can be made. Analysts can use several techniques and models to answer their process related questions. The steps of this process (the query) can be saved, so when the data are refreshed, the analysis can be updated.

The last section, the dashboard, is meant for tracking the organization's process performance. The analyst can develop certain queries. For example, the average lead time of preventive maintenance of a specific weapon system, and this can be loaded into the process-centric dashboard as a Key Performance Indicator (KPI). The dashboard periodically collects recent data from the ERP and the process owner can follow the progression. Based on the average process and on its excesses, the process owner can decide to intervene. Also, the (Kebede, 2015) developed a model to compare ProM, Disco, and Celonis on fifteen characteristics. The model was updated to the lasted tool versions and Celonis was replaced for ARIS PPM.

Table 1. Exhaustive list of process mining developers

Start	Software name	Software Developper	Country
2005	ProM	The Process Mining Group	The Netherlands
2007	ARIS Process Performance Manager	Software AG	Germany
2007	Interstage Automated Process Discovery	Fujitsu, Ltd.	Japan
2008	StereoLOGIC Discovery Analyst	StereoLOGIC	The United States
2009	The Process Mining Factory	Icris	The Netherlands
2010	Apromore	The Apromore Initiative	Australia
2011	Celonis Process Mining	Celonis GmbH	Germany
2011	Perceptive Process Mining	Perceptive Process Mining	The United States
2012	Disco	Flusicon	The Netherlands
2012	QPR Process Analyzer	QPR	Finland
2012	Process Mining Solution	Coney	The Netherlands

2013	SNP Business Process Analysis	SNP Schneider-Neureither & Partner AG	Germany
2013	minit	Gradient ECM	The United States
2015	myInvenio	Cognitive Technology Ltd.	Malta
2015	XMAnalyzer	XMPro	The United States
2016	Lana	Lana Labs GmbH	Germany
2017	ProcessGold	ProcessGold International B.V.	The Netherlands
2018	Kofax insights	Kofax INC.	The United States
2018	Appnomic OpsOne	Appnomic self-healing enterprise	India
2019	MPM process mining	Mehrwerk GmbH	The Netherlands
2020	EverFlow	Icaro Tech	Brazil
2021	UiPath Process Mining	UiPath	Romania

Table 2. Process mining compared to traditional BPI methodologies

Concepts	Process Mining (Mature version)
First mentioned	2015
Origin	The rise of big data and accessibility of computing power
Align	Align de facto with de jure process models
Process view	Discovering, conforming, and enhancing business processes
Involvement	Multidisciplinary team
Methodology	Plan, extract, process data, mine and analyze event data, evaluation, and process improvement & support in a team
Primary Effects	Gain quantitative and factual knowledge about processes
Secondary Effects	Improvements can be monitored and verified
Criticism	Demanding high quality data and structured processes

5. Discussion and Conclusion

A basic discussion of several traditional BPI methodologies has already been given in section 1. In this research, we compare process mining with these traditional methodologies. On one hand, they find their origin in Lean and while throughout the years many different BPI approaches arose, the boundaries between these BPI approaches remain vague. In this regard, many approaches have been combined to form new BPI approaches and users often interchange the terms. As a science, this makes it difficult to investigate their characteristics. An overview is presented to order eight widely used BPI approaches on nine properties.

This overview contributes to the knowledge on BPI. However, this is only the tip of the iceberg. Scholars and management consultants frequently come up with new BPI approaches and combine them till distinction is long gone. For example, next to Lean Six Sigma and Lean MRO (Maintenance Repair and Overhaul) the research shows us that the variations Lean Start-up, Lean Manufacturing, Lean Management, Lean Thinking, Lean Enterprise, and Lean Maintenance also are being used. These variations could be completely new methodologies, slightly adjusted methodologies, or identical to Lean as described in this chapter.

On the other hand, all discussed BPI approaches have a statistical or analytical background, but process mining excels in its ability to automatically convert data into organized information. It is hypothesized that PM is a mature BPI approach. In its short history, process mining has made an impressive development. Every year, more process mining tool is developed, papers on the topic are published, courses in process mining are given, and case studies are conducted (Gonella, 2017). Since process mining is a data driven activity, and with data storage becoming cheaper and cheaper and initiatives like the

Internet of Things (IoT) boosting data production, new possibilities do arise.

Mechanics can, for example, enter their activity data in the ERP with wireless tablets, giving real time analysis possibilities. Combining this with Artificial Intelligence (AI) and Machine Learning (ML) can offer even bigger opportunities. AI can find deviating process instances and even suggest improvements without human intervention. PM provides data on all activities of a process: its throughput, lead times, its delays, etc. These data can be used for building an accurate model in simulation tools. By reasoning, but also by trial-and-error, elements in the simulation can be changed till the model cannot be improved anymore. The changes can then be applied in the real world. Integrating process mining tools with simulation tool can create significant opportunities, and from the managerial standpoint, PM accumulates teams experiments to produce more significant results.

To conclude, all discussed BPIs have a statistical or analytical background, but process mining excels in its ability to automatically convert data into organized information. Compared with existing BPI methodologies, process mining had more computer capabilities to implement BP improvements results. However, there are several drawbacks that must be addressed. Indeed, these drawbacks will be discussed in the following chapter. They mainly concern event logs quality and business process structures.

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Bayesian Network Structure Discovery Using Antlion Optimization Algorithm.

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Abstract

Bayesian networks have recently been used for discovering an optimal learning structure in machine learning. Bayes networks can describe possible dependencies of explanatory variables. As a novel approach to studying the structure of a Bayesian network, the authors present the Antlion Optimization Algorithm (ALO). In the algorithm; deletion, rewind, insertion, and change are utilized to produce ALO to reach the best hull solution. Essentially, the technique used in the ALO algorithm imitates the antlions' behaviors while hunting. The suggested approach is contrasted with simulated Annealing, Simulated Annealing Hybrid Bee, Greedy Search Hybrid Bee, optimization inspired by Pigeon, and greedy search using the BDe Score function. The researchers also studied the representation of the confusion matrix of these techniques using different reference data sets. The findings of the assessments reveal that the proposed algorithm works better than the other algorithms and has better consistency and score values. As shown by the experimental evaluations, the proposed method has a more reliable performance than other algorithms (including the production of excellent scores and accuracy values).

Keywords:Bayesian Network, Metaheuristics, Antlion Optimization, Structure Learning, Hunting Search, Local & Global Search, Search and Score

1. Introduction

One of the simplified theoretical techniques for graphing the probabilistic framework of observed data in machine learning is Bayesian Networks (BN) (Junzhong, Wei, Liu, 2012). They can be defined and executed completely for purposes including; information design, inference, and argumentation (Fortier, Sheppard and Pillai, 2013). The structure of the Bayesian network is represented as a direct acyclic graph (DAG) which is designed based on two complementary parts; the structure and the parameters of the network. The structure represents dependencies between the variables and the parameters represent conditional probabilities. Discovering the learning structure of a Bayesian network is difficult without a proper search approach. Learning the optimal structure of a Bayesian network (BN) using a dataset is NP-hard class (Junyi and Chen, 2014). A direct acyclic graph (DAG) is the configuration of the Bayesian network, which is constructed based on two complementary parts; the network structure and parameters. Dependencies between the variables are expressed by the configuration and the parameters represent conditional probabilities. Without a proper search strategy, solving the learning structure of a Bayesian network is challenging (Margarritis, 2003). To analyze the space of BN structures, the score and scan method is used to continuously approximate all alternative network structures before the valid metric value is obtained.

Score-based processes focus on a network prediction function, possible data, and aim for a framework that optimizes the score, which is the target (Fast, 2010). Two key models are used to apply the score function approach: The Bayesian score and the information-theoretical score. In methods such as; Log-likelihood (LL), Bayesian Information Criterion (BIC), Normalized Minimum Likelihood (NML), Akaike Information Criterion (AIC), Minimum Description Length (MDL), and Mutual Information Tests (MIT), the information-theoretical score used. In several various methods, the Bayesian score was done, such as; BD (Bayesian Dirichlet), BDe (Bayesian Dirichlet ('e' for probability equivalence)), BDeu (Bayesian Dirichlet equivalent uniform ('u' for uniform joint distribution)), and K2 (Cooper and Herskovits,1992).

There are different search method approaches to simplify the issue of structure learning. These include the Ant Colony Algorithm for Optimization (Salama and Freitas, 2012), Particle Swarm Intelligence (Cowie, Oteniya, Cles, 2007), Bee Colony(Li and Chen, 2014), Hybrid Algorithm ((He and Gao, 2018)(Li, and Wang, 2017)(Kareem and Okur, 2018)), Bacterial Foraging Optimization (Yang, Junzhong, Liu, Jinduo and Yin, 2016), Simulated Annealing Algorithm(Hesar, 2013), Breeding Swarm Algorithm(Khanteymoori, Olyaee, Abbaszadeh and Valian, 2018), Genetic Algorithms(Larraiiaga, Poza, 1996), Pigeon Inspired Optimization(Kareem and Okur, 2019), Gene-Pool Optimal Mixing Evolutionary Algorithm (GOMEA) (Orphanou, Thierens, and Bosman, 2018), Elephant Swarm Water Search Algorithm (Kareem and Okur, 2020), Falcon Optimization algorithm (Kareem and Okur, 2021), Binary Encoding Water Cycle(Wang and Liu, 2018), Tightening Bounds(Fan, Malone, 2014), A* Search Algorithms(Malone, Wui, 2011), Scatter Search Documents(Patrick and Sahin, 2004), Quasi-Determinism Screening(Rahier, Marie, Girard, Forbes, 2019), Cuckoo Optimization Algorithm(Askari and Ahsaee, 2018), and Minimum Spanning Tree Algorithm (Sencer, Oztemel, Taksin and Torkul, 2013). Antlion optimization is a different case of metaheuristic methodology that can be applied in Bayesian networks for structure learning. As a novel approach to Bayesian network structure learning, this paper proposes and provides a comparative review of this process. ALO is applied in the different optimization problems like the parallel machine scheduling (Kilic and Yuzgec, 2019), governing loop of thermal generators (Gupta and Saxena, 2016), Optimal Reactive Power Dispatch (ORPD) problem (Mei, Sulaiman, Zuriani, 2015), and optimal route planning of unmanned aerial vehicles (Yao and Wang, 2017).

Because there are hundreds of nodes involved in high-dimensional data sets, which are now booming across a wide range of areas, the accompanying Bayesian network structure is very complex. Discovering the Bayesian network structure based on the data turns into an NP-hard problem. To acquire an ideal structure from complicated and high-dimensional data sets in a fair amount of time, one of the primary problems in Bayesian network research is to develop an effective structure learning approach that is both efficient and effective. For compared to an expert system based on empirical knowledge, the Bayesian network eliminates the uncertainty issue, which is particularly important when handling complicated problems, making it both more effective and intuitive to use.

Given that learning the network from data is generally considered to be an NP-hard optimization problem, it is necessary to find an efficient search algorithm; to this end, the heuristic algorithm, which has high search efficiency and is frequently used to find the best network structure in structure learning, has been developed.

Implementation of the stochastic search algorithm is straightforward, and the method's global search capability is enhanced. The global information may be employed more thoroughly than with other conventional search techniques, and the dependency on optimization function is less when compared to the other approaches. As a result, the network structure learned by the structure learning technique based on the stochastic search algorithm differs less from the actual structure and may converge to a better structure more rapidly, as well as the quality of the convergence itself is improved. The ALO has three major advantages: it can find a near-optimum solution independent of the starting parameter values, it has a quick convergence rate, and it can handle both integer and discrete constraints simultaneously.

The following is the layout of the remainder of this article. In Bayesian Networks, Part 2 discusses the principle of structure learning. A short introduction to the Antlion Optimization Algorithm is included in Part 3. We describe in part 4, the technique in-depth and demonstrate the experimental outcomes. The findings are found in Section 5.

2. Structure Learning of Bayesian Networks

Two components can be used to express the Bayesian Network: (G, P). The first, G (V; E), is the DAG that covers the calculable group of vertices (or nodes), V, interconnected by labeled edges (or connections), E. The second, P = {P (Xi Pa (Xi)))}, is a set of conditional probabilistic (CPD) distributions, entity to all Xi variables (chart vertices). In addition, Pa(Xi) represents the set of the node Xi parents in G (Cowie, Oteniya, Coles, 2007). A simple probabilistic combination for a (G; P) network can be represented based on this model via:

$$P(X_i, ..X_n) = \prod_{i=1}^{n} P(X_i|Pa(X_i)) \qquad (1)$$

On the other hand, a score function relies on many parameters, including Bayesian methods, data, and entropy, the minimum duration of explanation (Campos, 2006). Bayesian network posterior likelihood, according to Bayesian inference rules, can be expressed as:

$$P(G|D) = P(D|G)P(G)/\sum_{G'} P(D|G')\,P(G') \qquad (2)$$

In (2), P(D) is a conditional probability specified by using P(D) normalizing constant as:

$$P(D|G) = \int P(D|G,\theta)\,P(\theta|G)d\theta \qquad (3)$$

It is presumed that P(D) is independent of the Bayesian network G configuration. P(G) 'is the preceding likelihood, and θ represents the model parameter. As a result, the resulting distribution of the network configuration can be estimated as long as the marginal likelihood of all possible configurations is determined (Zhang, Liu, 2008). Structure learning approaches use score-based strategies by comparing the structure's existing and previous scores. The final expression of the ranking is (Heckerman, Geiger, and Chickering, 1995):

Score (G, D)=∑Score(Xi, Pa(Xi), D(Xi, pa(Xi))) (4)

3. Antlion Optimization Algorithm

Metaheuristics are algorithms motivated by nature to find approximate solutions to certain computationally complicated problems of optimization. In metaheuristics, swarming activities of firefly-BATT (Gadekallu, and Khare, 2016), cuckoo (Gadekallu, and Khare, 2017), ant, pigeon, fish, bee, etc. were used, (Gandomi, Yang, Marand, and Alavi, 2013). Some of the metaheuristic methods' supporting properties include adaptability, homogeneity, illation-free resources, and local optima eschewal ability (Mirjalili, Mirjalili, Lewis, 2014).

One of the newly proposed metaheuristic methods is Antlion Optimization (ALO) (Mirjalili, 2015). This is a life-cycle-based search algorithm inspired by evolution. The ALO algorithm simulates the relation in the trap area between antlions (doodlebugs) and ants. Ants are expected to walk blindly around the search area and antlions are often ready to hunt them and in time they become competent with traps. The ALO algorithm aims to model, the combat techniques used by antlions. The antlion's life cycle consists of two main levels: larvae and adults. Normally, antlion life can be rated for up to 3-4 years, which is effectively spent at the larval stage. In the larval and developmental stages, they search for prey daily. Antlion primarily uses five steps to hunt prey, including; arbitrary movement of ants, creation of traps, trapping of ants, hunting of prey, and traps reconstruction (Nischal, Mehta, 2015). In the ALO algorithm ants represent possible arbitrary solutions to a particular problem within the search field and antlion holes to pick up and eat ants in the ground. The ability to chase ants is coded and programmed according to the relationship between the ants and the antlion in the objective role. When describing optimization using the essence of the hunting abilities of antlions, there are impressive actions to consider. Inside the search field, the random motion produced by ants in ALO concerns the locations of ants and antlion-generated holes in the dimensions. The measurements of the cone-shaped hole are proportional to every antlion's health, i.e. the fitter antlions can create stronger holes and thus have a greater chance of capturing prey. The ants will pass into any antlion trap and adaptively decrease the size of their random motion as the antlion slides the ants towards the bottom of the pit. As a result, the eating antlions grow fitter than preys, use their position and restore the hole to maximize their chance of capturing other ants (Zawbaa, Emary, Parv, 2015) (Yogarajan, Revathi, 2016). This approach, which is based on the deep neural network (DNN) model, is used to pick ideal hyperparameters while using the least amount of time. An additional advantage of the suggested model was that it required just 38.13 percent of the total training time. It was shown via testing that the suggested paradigm was more effective (Gadekallu, Bhattacharya, Praveen, Zada, et. al.2020). ALO-SVR, a technique based on ant lion optimization algorithm and support vector regression, was developed to increase lithium battery SOH estimate accuracy. The Pearson correlation coefficient is used to examine the association between features and SOH in this technique, which picks characteristics that are strongly connected with current, voltage, and temperature. The Ant Lion Optimization Algorithm is used to refine the SVR model's main parameters before a final estimate model is developed. The findings reveal that the ALO-SVR approach has greater estimate accuracy and stability than the current GA-SVR and GS-SVR on the NASA public data set, proving the practicality of the estimation method. This research proposes the implementation of Multi-Objective Antlion Optimization (MALO) on solving Flight Scheduling and Aircraft Routing in the current pandemic conditions. The result showed an improvement in the estimated number of passengers and a decrease in the total cost. The result also revealed that MALO is capable of outperforming other well-known optimization algorithms and converged faster in the large data group while able to work faster than Genetic Algorithm (GA) across all experiments, proving MALO to be a more suitable method when dealing with large scheduling task (Awalivian, Raihan, Suyanto and Siti, 2021). Problems that the Ant Lion optimization method easily falls into the local optimum are the focus of this paper's discussion of dynamic random hill-climbing. By using hill-climbing mechanisms, an ant lion's jumping capacity is enhanced. By balancing exploration and development, a dynamic hill-climbing mechanism improves the algorithm's global search capabilities (GU, 2020).

The following conditions are assumed for the optimization process:

- Ants walk in the search area utilizing several arbitrary routes.
- Arbitrary walking is applied to every dimension of ants.
- Walking at random is affected by antlion traps.
- Antlions can create holes that fit their fitness (more powerful fitness, bigger hole).
- The possibility of grabbing more ants in large holes is higher.
- The fittest antlion will trap each ant in repetition.
- To mimic sliding ants in the direction of the antlion, the subjective movement scale has been adaptively decreased.
- When an ant grows fitter than antlion, it suggests that under the sand it is trapped and pulled by antlion.
- The antlion remains near the last captured prey and creates a pit to maximize its chance of capturing another prey.
- The mathematical model of ant is explained as follows, while exploring the region for food, ants walk at random (Kilic, Yuzgec, Karakuzu, 2019):

$$X(i)= [0, cusum(2r(i1-1)), cusum(2r(i2-1)), ..., cusum(2r(iT-1))] \quad (5)$$

cusum denotes cumulative sum, T is the largest number of iterations, where X(i) is the random movement of ants at iteration I and r(j) is an arbitrary function represented as:

$$r= \begin{cases} 1 & if\ rand > 0.5 \\ 0 & if\ rand \leq 0.5 \end{cases} \quad (6)$$

in the interval [0, 1], where rand is a random integer. The locations of ants are modified at each iteration, depending on the mechanism of random motion.

According to the upper and lower values, the spontaneous movement of ants should be normalized into the location in the real quest field. It is possible to determine the position of ants by using the following formula for each iteration.

$$X_i^t = \frac{(X_i^t - a_i)(d_i^t - c_i^t)}{b_i - a_i} + c_i^t \quad (7)$$

Where ai and bi are the minimum and maximum random motion values of ant and d_i^t, c_i^t denote the minimum and maximum location values of the antlion at the iteration of ith. X_i^t is standardized by the use of [0,1] $\frac{(X_i^t - a_i)(d_i^t - c_i^t)}{b_i - a_i}$. This shows the location of the selected antlion nearby. The ant walk is influenced by the antlion; the antlion hunts and drags it down to the pit as soon as the ant reaches the trap.

This procedure's mathematical model can be interpreted as follows (Kilic, Yuzgec, Karakuzu, 2019):

$$c_i^t = C^t + Antlion^t, \qquad d_i^t = d^t + Antlion^t \quad (8)$$

$$c^t = \frac{c^t}{I}, \qquad d^t = \frac{d^t}{I} \quad (9)$$

The antlion is the antlion location for each chosen antlion at the t^{th} iteration while d^t and c^t is the maximum and minimum for all variables relating to the i^th^ ant, and I is the unique constant ratio based on the iteration as seen in various scenarios:

$$I = \begin{cases} 1+10^2\frac{t}{T} & \text{if } 0.1T < t < 0.5T \\ 1+10^3\frac{t}{T} & \text{if } 0.5T < t < 0.75T \\ 1+10^4\frac{t}{T} & \text{if } 0.75T < t < 0.9T \\ 1+10^5\frac{t}{T} & \text{if } 0.9T < t < 0.95T \\ 1+10^6\frac{t}{T} & \text{if } 0.95T < t < T \\ 1 & \text{otherwise} \end{cases} \quad (10)$$

where T is denoted as the maximum iteration, and the current iteration is denoted as t. While calculating the X_i^t from equation 7, ants walk nearby to antlion and elite antlion, picked by the roulette wheel principle, in the current population. Ants' new locations are measured by the following equation as follow:

$$(11) \quad Ant_i^t = \frac{R_A^t + R_E^t}{2}$$

where R_A^t is arbitrary movement nearby antlion picked by the roulette wheel in the t-iteration, and R_E^t is the arbitrary movement nearby the elite antlion in the t-iteration. The antlions are needed to update their position to the last ant site to be caught to enhance the possibilities of catching new prey. It is described by the following equation:

$$Antlion_j^t = Ant_i^t \quad \text{if} \quad f(Antlion_j^t) > f(Ant_i^t) \quad (12)$$

where f($Antlion_j^t$) and f(Ant_i^t) denotes the fitness function of the current iteration of Antlion and Ant, $Antlion_j^t$ i indicates the j^th^ ant position specified at the t^th^ iteration and Ant_i^t indicates the position of i^th^ ant at t^th^ iteration.

The locations of ants are collected and stored in the matrix M_{ant} which is utilized for the optimization problem. Similarly, the positions of antlions are stored in the matrix $M_{antlion}$, which is shown as follow:

$$M_{ant} = \begin{bmatrix} Ant_{1,1} & \cdots & Ant_{1,d} \\ \vdots & \ddots & \vdots \\ Ant_{1,n} & \cdots & Ant_{n,d} \end{bmatrix},$$

$$M_{antlion} = \begin{bmatrix} Antlion_{1,1} & \cdots & Antlion_{1,d} \\ \vdots & \ddots & \vdots \\ Antlion_{1,n} & \cdots & Antlion_{n,d} \end{bmatrix} \quad (13)$$

where the $Ant_{i,j}$ denotes to the value of ith ant at jth iteration, and $Antlion_{i,j}$ denote to the value of i^th^ antlion at j^th^ iteration. n denotes the number of ants also antlions, d represents the number of variables (Kilic, Yuzgec, Karakuzu, 2019). The (F) is fitness function of the ants and antlions are determined and saved in the F_{ant} and $F_{antlion}$ matrix as follow:

$$F_{ant} = \begin{pmatrix} f(ant_{1,1}, ant_{1,2}, \dots ant_{1,d} \\ f(ant_{12,1}, ant_{2,2}, \dots ant_{2,d} \\ \vdots \\ f(ant_{n,1}, ant_{n,2}, \dots ant_{n,d} \end{pmatrix},$$

$$(14) \quad F_{antlion} = \begin{pmatrix} f(antlion_{1,1}, antlion_{1,2}, \dots antlion_{1,d} \\ f(antlion_{12,1}, antlion_{2,2}, \dots antlion_{2,d} \\ \vdots \\ f(antlion_{n,1}, antlion_{n,2}, \dots antlion_{n,d} \end{pmatrix}$$

4. Learning Structure of Bayesian Network Based on ALO

As a quest tool for the structural learning of Bayesian networks, the proposed method incorporates the Antlion Optimization (ALO) technique. For the measurement of the Bayesian network structure, the BDe metric is used as a score function. The ALO algorithm is essentially an iterated process consisting of a population of entities where a possible location in a given space is encoded by any antlion. The search area is known to be the space. In nature, the ALO algorithm simulates the chase process of antlions. By walking around a roundabout path and driving the sand with a wide jaw, antlion larvae generate a conical hole in the ground. The larvae shelter below the bottom of the cone after drilling the trap and readily anticipate their insect to pass through the hole as seen in Figure 1. It is removed and degraded as the prey is captured. When an ant approaches the cone, the antlion throws sand over the ant to slide it to the bottom of the hole. The antlion then raises the distance for the next catch. The ALO algorithm is defined as a function of three rows that converge as follows with the global optimum of optimization issues: ALO (A; B; C), where A is a function that produces arbitrary initial solutions, B, when reaching the ultimate norm, treats the first set given by function A and C. The antlion and ant are randomly generated in the ALO algorithm. The location of each ant relative to the antlion chosen by the roulette wheel operator and elite is changed at each iteration. The threshold for site changes is specified first about the current number of iterations. Then, by two random rounds of chosen ants and elites, the revised site is implemented. If all the ants walk randomly, a fitness function is used to estimate them. If any of the ants are more desirable than any other ant, their locations in the next iteration are intended to be new sites for the ants.

The best antlion is connected to the best antlion generated during optimization (elite) and is, if necessary, substituted. Such steps are iterative before false returns.

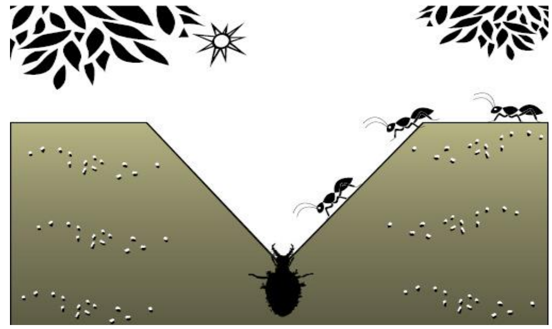

Fig. 1. the hunting process and behavior of antlion. (Anas Atef Amaireh, Asem Alzoubi, Nihad I Dib, 2017).

For each possible DAG, the Bayesian network solution region is generated for structure learning. For a given problem in the search space, the ants in the ALO algorithm represent the potential random solutions and the Antlions drill holes in the ground to trap and eat ants. An antlion’s hunting capacity is encoded in the objective feature and is optimized based on the relationship between ants and antlions. When modeling the optimization problem using the essence of the hunting activity of antlions, there are several laws to consider. A potential solution that represents a DAG having empty arcs is initiated by any antlion within the swarm. The exploration area for the roughly near-optimal or optimal solution, known as the BDe score, is later analyzed by an antlion. Equation (4) is used as the target function of the optimization to determine the BDe score. The goal of the exploration is to obtain a greater BDe score for the structure of the network. The initial solutions are created by iterative operations and the search space boundary is chosen. The arcs are appended one after another, beginning with a null graph (G0), given they are not included in the current graph solution. The append operation is done only if the new solution's score function is greater than the current score and the new solution also meets the DAG constraint. This approach proceeds until the sum of the arcs equals the amount specified in advance. The solution begins to allocate a population for each operator in the model and chooses the solution with a higher score function. According to the chosen operator, Antlion continues until the method has completed a sufficient number of iterations or no longer raises the BDe score. In local optimization, the processes usually involve four different operations: Elimination, Extension, Reversion, and Movement, as seen in Figure 2. Within this domain, the first three are basic operations, requiring only replacing an individual edge from a rival solution every time. This causes a relatively small region near the solution to be used. On the other hand, the existing edges modify the collection of parents for any movement process, which will allow a moderately significant change for the current solution. Therefore, if, after applying basic operators, the solution is not modified, the moving operator will boost it. Walking is the key force in local optimization using the preferred operation, which expands more as an antlion reaches the desired solution.

Walking directions, the turn of different local optimization operators, is becoming more widespread as an antlion constantly travels from a solution to a stronger one by experimentation. An antlion G0, which represents a DAG with arcs, attempts reversion, movement, extension, and deletion as seen in Figure 2, and reaches new G1, G2, G3, and G4 solutions, respectively. It will pick, thinking the best score is in G3, and it will begin to explore a similar method to get G+3 as the new solution. If G+3's BDe score is greater than that of G+1, the subsequent operator will continue to perform. Until the BDe score stabilizes, the operations can repeat, or the iteration loop completes the limit. The antlion chooses Elimination, Extension, Movement and Reversion among the directions in the entire process. The ALO algorithm pseudocode is seen in figure 3.

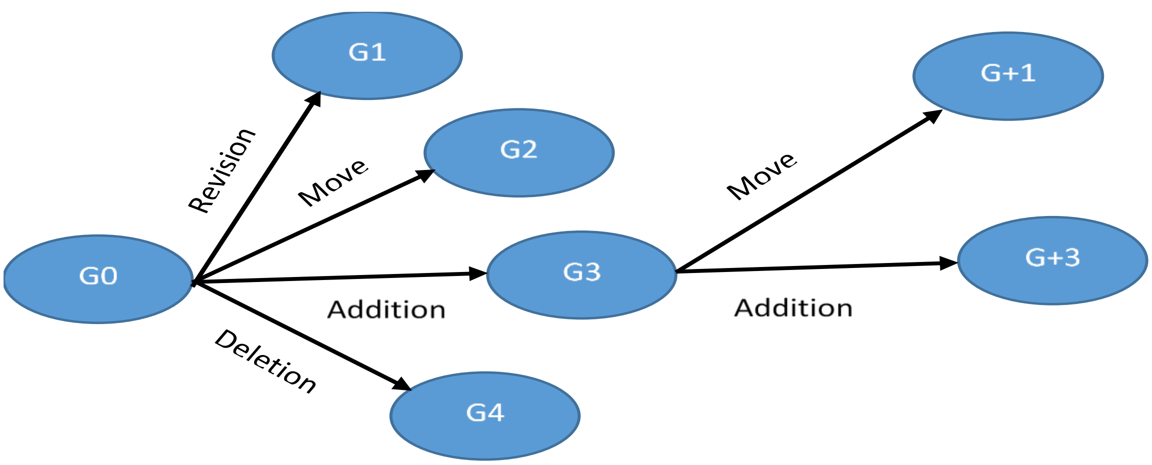

Fig. 2. Hunting searching steps for ALO

Algorithm: Antlion Algorithm for Bayesian Network Structure Learning.
INPUT*: - datasets*
NE: The size of the population
D: search space dimension
Search range: the search space border
tmax: maximum number of iterations; X_{max}*: upper boundary, and* X_{min}*: - lower boundary*
OUTPUT*: - Structure learning Bayesian Network with BDe Score of Best Structure.*

(1) The initialized empty structure and initialize parameters of ALO algorithm (dimension space D, size of population NE, the number of iteration, upper boundary (X_{max})and lower boundary (X_{min}), and $X_{max} > X_{min}$.

(2) Comparing each antlion by BDe score function, and find the elite antlion in the current position ($P^t_{best, i, d}$).
(3) While the end criterion is not satisfied
I. Find a new best position by comparing the BDe score function of each antlion, through updating the c^t_i, d^t_i in using equation (8)
II. Create a random walk and normalization using equation (5) and (7)
III. Update the antlion position using equation (11).
(4) Calculate the BDe score function.
(5) Evaluate BDeu score function of the new position using equation (12).
a. If the new position is better than the best, so the best position is updated.
b. If the (best global position) < current position, then update the best solution for global
c. The best score value and solution are saved.

d. If Xmin $\geq$ Xmax, stop the iteration process, and the results are present. If not, move into Step 5.
(6) Return the maximum BDe score.

Fig. 3. ALO Algorithm for Bayesian network structure learning

5. Experimental Evaluation

A common validation methodology is used to test the algorithm efficiency of ALO by using probabilistic datasets derived from famous Bayesian network benchmarks. A PC with the following properties is used in the experiment platform: Core i3, 2.1GHz Clock, 4 GB RAM, Ubuntu 14.04 operating system and uses Java to execute the algorithm. In multiple static datasets, the authors investigated the properties of the proposed algorithm, including; Andes (500 instance, 338 arcs, and 223 variables), Lucap02 (10000 instance, and 143 variables), win95pts (574 instance, 112 arcs, and 76 variables), Hepar (350 instance, 123 arcs, and 70 variables), Hailfinder (2656 instance , 66 arcs, and 56 variable), Alarm (10000 instance, 46 arcs, and 37 variables), Soybean (307 instance and 35 variables), Hepatitis(137 instance and 35 variables), Static Banjo (320 instance and 33 variables), Water (10083 instance, 66 arcs, and 32 variables), Epigenetics (72228 instance and 30 variable), Insurance (3000 instance, 52 arcs, and 27 variables), Sensors(5456 instance and 25 variables), Mushroom (1000 instance and 23 variables), Parkinsons (195 instance and 23 variables), Heart(267 instance and 22 variables), Imports(205 instance and 22 variables), Child (230 instance, 25 arcs, and 20 variables), Letter (20000 instance and 17 variables), Adult (30162 instance and 16 variables), Lucas01(10000 instance and 10 variables), WDBC (1000 instance and 9 variables), and Asia (3000 instance, 8 arcs, and 8 variables) (Kareem and Okur, 2019). This study is based on the stationary data presumption in the present form, and stationery sets are the learning datasets that we considered. It is a difficult job to apply the ALO algorithm to sensor data sets or other kinds of online stream data sets and should be tried after testing its output over stationary data sets. It is a difficult job to apply the ALO algorithm to sensor data sets or other kinds of online stream data sets and should be tried after testing its output over stationary data sets. Pigeon Inspired Optimization (PIO) (Kareem and Okur, 2019). Hybrid Simulated Annealing with Bee (BSA) (Kareem and Okur, 2017), Simulated Annealing, Hybrid Greedy with Bee (BGS) (Kareem and Okur, 2018), and Greedy Search methods are correlated with the performance of ALO by using the respective data set metrics. Both algorithms under the same conditions were tested by the authors. Global and Local searches are added to the datasets after specifying the parameters of the ALO algorithm. Population size N=50 and tmax = 10000 are both fixed parameters of ALO optimization for each event. The simulated annealing algorithm parameters are as follows: re-annealing temperature = 500, cooling factor = 0.8, original temperature = 1000. Greedy quest parameters are as follows: recommended maximum networks before reboot = 5000, suggested minimum networks before reboot = 3000, reboot by random network = yes, recommended minimum networks after maximum score = 1000 maximum parent count for operations Reboot = 5. Pigeon parameters are the search space dimension (D=20), the number of pigeons (NP=300), the maximum number of iterations for the map and compass operation (Nc1max=5000), the map and compass factor (P=0.3), and the maximum number of iterations for the landmark operation (Nc2max=10000). The Bee algorithm parameters are: Number of Scout Bees n= 200, Number of repetitions of algorithm steps imax= 10000, Number of best site e out of m chosen site= 7, Number of Sites m out of n visited sites= 30, Number of Bees needed for best e site n2= 90, Initial size of patches ngh including randomly chosen site= 200, Number of Bees needed for the other site (m-e) (n1) = 30. Three separate execution times have been applied by the algorithms: 60, 5, and 2 minutes.

In the data sets and time values listed, the results in Table 1,2,3 indicate the score for each algorithm. It can be observed from these tables that the approach suggested yields better score values for all conditions than the default Greedy Search, and Simulated Annealing Algorithms.

Table 1. The ALO, Simulated Annealing, PIO, Hybrid Bee with Simulated Annealing, Hybrid Bee with Greedy, and Greedy Score function in 2 minutes Execution time.

Dataset	**2 Minutes**					
	ALO	**PIO**	**Simulated Annealing**	**Hybrid Bee with Simulated Annealing**	**Greedy**	**Hybrid Bee with Greedy**
Asia	**-55049.9**	-55269.5	-56340.3	-56158.6	-56340.3	-56258.7
WDBC	**-6658.43**	-6666.04	-6682.72	-6675.42	-8089.41	-8080.83
lucas01	-11863.1	**-11860**	-12243.2	-12235.3	-13890.9	-13795.3
Adult	**-207805**	-207809	-211678	-211670	-211844	-211850
Letter	**-175185**	-175200	-178562	-178550	-184307	-184205
Child	-62364	**-62362**	-62343.7	-62341.8	-63336.6	-63325.2
Heart	-2424.49	**-2423.8**	-2432.19	-2423.8	-2576.93	-2570.56
Imports	**-1811.99**	**-1811.99**	-1828.91	-1820.26	-1994.15	-1982.59
spect.heart	**-2141.05**	-2142.5	-2141.47	-2141.23	-2144.65	-2144.2
Parkinson's	**-1488.52**	-1598.91	-1601.3	-1600.92	-1732.76	-1715.57
Mushroom	**-3162.28**	-3372.51	-3375.31	-3374.18	-3745.46	-3745.46
Sensors	**-60341.9**	-60343.3	-60710.5	-60508.7	-69200.3	-68962.5
insurance	**-13896.4**	-138997	-13872.3	-13870.6	-13904.6	-13904
Epigenetics	**-176641**	-176657	-179910	-179906	-225346	-225340
Water	**-11563.4**	-13269.5	-13290.8	-13262.6	-14619.1	-13262.8
static. Data	-8427.12	**-8425.72**	-8451.5	-8449.49	-8585.21	-8570.26
Hepatitis	**-1326.58**	-1327.73	-1330.47	-1329.97	-1350.16	-1346.5
soybean	-2870.3	**-2870.2**	-2870.85	-2859.13	-3021.41	-3025.82
Alarm	-105155	**-105150**	-104927	-104927	-105972	-105552
Hail finder	**-75592.4**	-89521.6	-148193	-148180	-153602	-152038
Hepar	**-160095**	**-160095**	-161086	-161050	-169497	-161051
win95pts	**-46772.8**	-46779.5	-47085.1	-47032.4	-83749.3	-83650.8
Lucap2	**-112982**	-186368	-112261	-111413	-151215	-151243
Andes	**-498180**	-613197	-497353	-477461	-591871	-589927

Table 2. The ALO, Simulated Annealing, PIO, Hybrid Bee with Simulated Annealing, Hybrid Bee with Greedy, and Greedy Score function in 5 minutes Execution time.

ataset	5 Minutes					
	ALO	**PIO**	**Simulated Annealing**	**Hybrid Bee with Simulated Annealing**	**Greedy**	**Hybrid Bee with Greedy**
Asia	**-55157.2**	-55852.6	-56340.3	-56218.5	-56340.3	-56320.9
WDBC	-6662.24	**-6666.04**	-6682.72	-6675.52	-7954.65	-75236.7
lucas01	**-11512.5**	-11892.5	-12243.2	-12229.7	-12243.2	-12230.4
Adult	**-207328**	-207809	-211678	-211664	-211781	-211756
Letter	**-175200**	**-175200**	-178562	-178523	-184916	-182584
Child	**-62363.8**	-62369.2	-62343.7	-62140.7	-63799.4	-63235
Heart	-2424.81	**-2423.8**	-2423.8	-2423.8	-2560.43	-2545.2
Imports	**-1811.99**	**-1811.99**	-1828.91	-1824.3	-2012.21	-1950.3
spect.heart	**-2129.27**	-2132.82	-2143.73	-2140.85	-2142.89	-2141.25
Parkinson's	**-1441.27**	-1598.91	-1601.3	-1600.58	-1721.16	-1701
Mushroom	**-3162.45**	-3372.51	-3375.31	-3375.51	-3709.7	-3625.4
Sensors	**-60343.3**	**-60343.3**	-60710.5	-60642.2	-69150	-66250
insurance	**13895.11**	**-13895.1**	-13872.3	-13842.7	-13904.6	-13892.3
Epigenetics	**-176637**	-176657	-179300	-179296	-224172	-224162
Water	**-11564.4**	-13269.5	-13290.8	-13262.6	-14644.7	-13264.5
static. Data	**-8414.4**	-8425.2	-8449.77	-8445.41	-8561.93	-8448.24
Hepatitis	**-1327.73**	**-1327.73**	-1330.47	-1328.62	-1350.16	-1340.3
soybean	**-2973.3**	**-2973.3**	-2857.82	-2863.82	-3011.38	-2991.81
Alarm	**-105167**	-105182	-104927	-104927	-106114	-106171
Hail finder	**-75583.9**	-75698	-148188	-148179	-153075	-151863
Hepar	**-160095**	**-160095**	-161086	-161049	-169881	-163375
win95pts	**-46779.5**	**-46779.5**	-47085.1	-47023.7	-83150.7	-75201.5
Lucap2	**-110425**	-175635	-112217	-110834	-152092	-151913
Andes	**-48572**	-613180	-489796	-480065	-588503	-584605

Table 3. The ALO, Simulated Annealing, PIO, Hybrid Bee with Simulated Annealing, Hybrid Bee with Greedy, and Greedy Score function in 60 minutes Execution time.

Dataset	60 Minutes					
	ALO	**PIO**	**Simulated Annealing**	**Hybrid Bee with Simulated Annealing**	**Greedy**	**Hybrid Bee with Greedy**
Asia	**-30584**	-30850	-56340.3	-56340	-56340.3	-56340
WDBC	-6662.25	-6666	-6682.72	-6679.63	-7841.35	-7752.35
lucas01	-11213.8	**12115.38**	-12243.2	-12212.9	-12243.2	-12236.4
Adult	**-207457**	-207809	-211678	-211664	-211762	-211739
Letter	**-175200**	**-175200**	-178562	-178510	-184118	-182269
Child	**-62245.7**	-62275.2	-62343.7	-62312.4	-63799.4	-63756.9
Heart	**-2422.57**	-2423.8	-2432.19	-2423.8	-2527.44	-2522395
Imports	**-1811.25**	-1812	-1828.91	-1824.3	-1995.76	-1950.2
spect.heart	**-2130.87**	-2135.4	-2144.13	-2144.1	-2142.24	-2142.24
Parkinson's	**-1442.87**	-1598.9	-1601.3	-1695.25	-1700.36	-1693.58
Mushroom	**-3019.91**	-3372.5	-3375.31	-3374.57	-3588.69	-3524.83
Sensors	-60343.3	**-60343**	-60710.5	-60612.5	-68364	-67825
insurance	**-13912.7**	-13950	-13872.3	-13850.6	-13904.6	-1385.62
Epigenetics	**-176642**	-176657	-179300	-179296	-217246	-217212
Water	**-11812.7**	-13270	-13290.8	-13262.2	-14272	-13262
static. Data	**-8325.27**	-8368.4	-8445.36	-8552.37	-8556.7	-8552.4
Hepatitis	**-1327.7**	**-1327.7**	-1330.47	-1328.62	-1350.16	-1346.52
soybean	**-2973.3**	**-2973.3**	-2973.83	-2992.99	-3012.72	-2993
Alarm	**-104884**	-104915	-104927	-105271	-105377	-105271
Hail finder	**-75852.4**	-78293	-148183	-151773	-152299	-151773
Hepar	**-160095**	**-160095**	-161086	-163231	-168871	-163231
win95pts	**-46780**	**-46780**	-47085.1	-470016	-83150.7	-80253.4
Lucap2	**-105289**	-105621	-111275	-151160	-150938	-151160
Andes	**-469254**	-469342	-480491	-480253	-586760	-587098

This means that with the minimal time needed, the ALO finds the best score. Another achievement of ALO optimization is observed for various values of population and the highest repetition quantity of the algorithm. The value of population and highest iteration number chosen of these sets {50, 75, 100, 1000, 2000, 3000, 4000, 5000}, respectively. It is observed that the score function is completely satisfying for all datasets. Furthermore, for some datasets, increment in the highest repetition number has less effect on score fitness. Nevertheless, if increase the population number, the score function weakens considerably. But, the increase in population and the repetition amount will reach to larger computational time. The confusion matrix is often used to measure the success of structure discovery. Using existing network architectures, each algorithm and data set may be assigned a confusion matrix value. It is the goal of this study to make a direct comparison between an existing network's structure and the one being constructed. To generate the confusion matrix, we first require a collection of predicted networks that can be compared with the real network. There are rows for the actual classes and columns for the expected classes in a confusion matrix. We need to construct the confusion matrix for each data set and its known network structure to verify the effectiveness of structure discovery.

The confusion matrix was being measured with each data set and its identified network structure to determine the performance of structure discovery. For each network, per algorithm, the metrics TN, TP, FP, and FN, were determined as well as the criteria; AHD, Accuracy (ACC), F1 Score, and Sensitivity (SE), defined as:

$$AHD = \frac{FN+FP}{TP+TN+FP+FN} \quad (15)$$

$$F1Score = \frac{2*TP}{2TP+FP+FN} \quad (16)$$

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \quad (17)$$

$$Sensitivity = \frac{TP}{TP+FN} \quad (18)$$

The definitions of certain criteria would be as follows: The FN is the arc in the routine, but not in the learning network. FP is the arc that is not in the normal network within the learning network. In neither the learning network nor the normal network, TN is the arc inside A TP is an arc (vertex or edge) within the learning network in the correct position.

In Figure 4, the sensitivity outcomes for ALO, PIO, Simulated Annealing and Greedy are shown. In the multiple datasets, the suggested strategy yields better values than PIO, Virtual Annealing and Greedy. Similarly, as seen in Figure 5, the suggested approach has high precision values in most datasets relative to the Simulated Annealing and Greedy algorithms. In finding the required structure, the proposed ALO Learning Algorithm performs well. As a consequence, the Iterative ALO algorithm is the best in most datasets from the point of estimation accuracy relative to other algorithms, and the ALO is even greater than the other algorithms from the point of construction times. For success indicators, we used F1 as a measure of the model's precision, in addition to the best score in Bayesian results. To measure the efficiency of the proposed algorithm, the F1- score, Accuracy, and Recall are used. In these cases, accuracy is the number of correctly identified guided edges divided by the number of all the edges in the predicted BN. The Recall is a partition of the number of directed edges identified in the real BN by the number of edges. It is known that the harmonic average of precision and recall is F1. The comparison of ALO is presented in figure 6, Greedy search, and Simulated Annealing. Perfection in these cases may be measured by finding all directed edges in a given BN and dividing it by the number of edges in the predicted BN. The number of directed edges detected divided by the total number of edges in the BN is what is represented by the Recall. Precision and recall, which constantly range between zero and one, make up the F1-score.

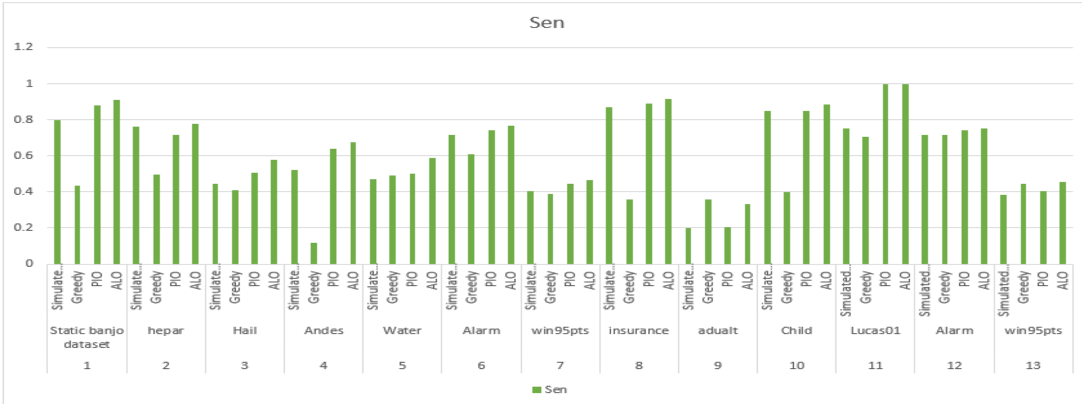

Fig. 4. Sensitivity for ALO, PIO, Simulated Annealing, and Greedy.

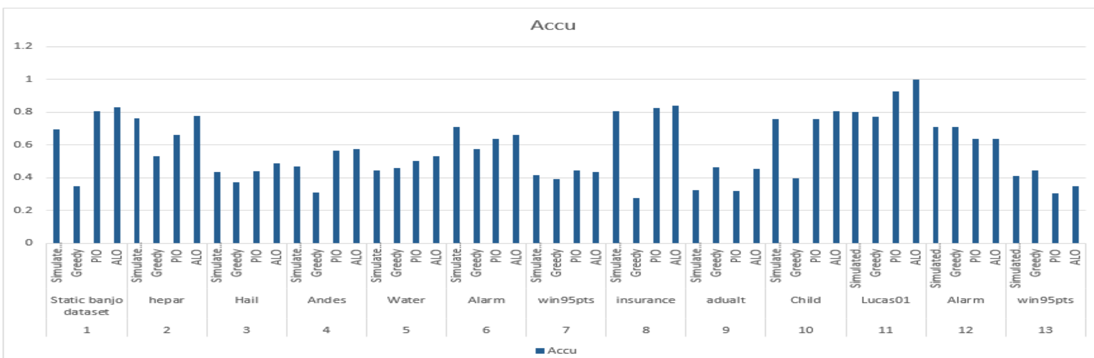

Fig. 5. Accuracy for ALO, PIO, Simulated Annealing Greedy

At 1 an F1 score is at its highest value, while at 0 it is at its lowest. The proposed methods are successful, as seen in Figure 6, than the Greedy search and Simulated Annealing Methods.

In addition, the model's ultimate aim is to provide a convenient representation of the real world, so consistency is a valuable model performance measurement metric.

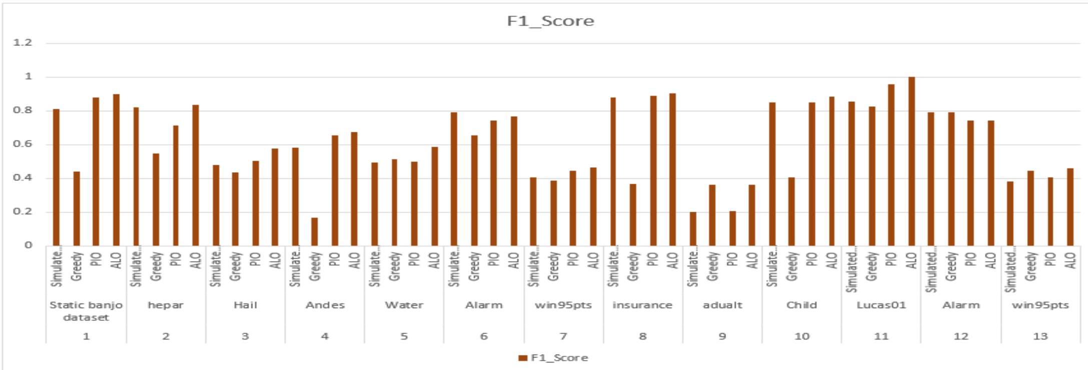

Fig. 6. F1_ Score for ALO, PIO, Simulated Annealing Greedy

The Hamming distances obtained by utilizing the DAG space are always much smaller than those obtained by using the suggested approach. As one of the most often used assessment measures for BN-structured learning, hamming distances fit the structure of students and the real networks, and they are focused exclusively on exploration rather than inference. The findings show that the suggested strategy outperforms the other methods that we've studied in terms of performance. Error correction often makes use of the Hamming distance.

From the Hamming distances, which are often considerably lower than those obtained by using the DAG space, the suggested algorithm is also preferable. Hamming distances are one of the most often used assessment criteria for BN structure learning, and often explicitly fits the learners' configuration and local networks are entirely geared towards discovery rather than inference. For the listed algorithms, Figure 7 shows the Average Hamming Distances. The findings suggest that the approach proposed provides higher output values than the other approaches we have considered

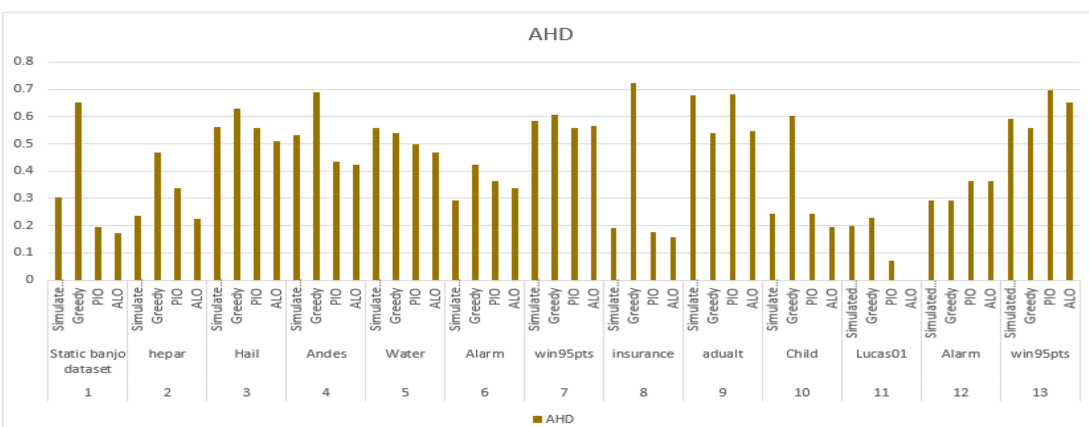

Fig. 7. AHD for ALO, PIO, Sim-

6. Conclusion

The authors concentrated on the learning issue of the Bayesian network structure and introduced the Antlion Motivated Optimization method for Bayesian network structure learning. The score and check strategy is used, using the ALO technique as a search and BDeu as a function of the score. ALO can be defined as a stochastic search method based on antlions' navigational behaviors. ALO is a general method of looking for a separate solution space; it can therefore be modified to accommodate any implementation field. Concentration management in ALO provides the global extremum with improved concentration by allowing the antlion to travel to the shortest available solution space. The suggested approach has a higher search capability, which means that better structure solution can be detected, higher score feature values measured, an excellent approximation to the structure of the network, and the results are correct. Algorithms accelerate global quest and easily contribute to global convergence. We expect to analyze other important ALO characteristics such as: run time analysis, use of energy, overall performance using additional data sets and experimental setups.

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Facilitating multidirectional knowledge flows in project-based organizations: the intermediary roles of project management office

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Abstract

Project-based organizations (PBOs) have been widely recognized as powerful generators of knowledge and innovation owing to their autonomous, multidisciplinary, and goal-oriented operations in the form of projects. However, evidence shows that PBOs are likely to suffer a knowledge flow gap between operational and strategic management levels leaving much of PBOs' knowledge trapped within project boundaries. Although several studies advocated the use of project management office (PMO) to enhance the interaction between these levels, very few examined PMO knowledge brokering roles. This study therefore tries to synthesis theories and evidence around PMO knowledge brokering roles to produce a theoretical understanding on how PMO managers mediate every knowledge flow transaction in PBOs. A theoretical model identifying three key levels of knowledge flow transactions, each of which is mediated by a set of knowledge brokering roles, has been developed. The model heights the powerful potentials of PMO knowledge brokering roles in governing PBOs' knowledge by balancing bottom-up explorative with top-down exploitative knowledge flow transactions. Theoretical contributions, practical implications and future research directions have also been outlined as part of this study.

Keywords: knowledge brokering; project management office; project-based organizations

1 Introduction

Knowledge has long been recognized as the most valuable resource determining how tangible resources are allocated to handle every single issue in organizations (Alavi & Leidner, 2001). That is, employees' specialist knowledge needs to be elicited, integrated and exploited to support decision-making and in turn achieve competitive advantages (Grant, 1996). Since traditional organizational forms are more professionally clustered, integrating different professional views can be more challenging and time-consuming. The increasingly fierce market competition and the pressing need to knowledge generation and innovation, therefore, necessitated a growing number of organizations to adopt more project-based structures (Sydow, Lindkvist and DeFillippi, 2004; Kerzner, 2005; Mueller, 2015).

PBO is a form of organizing in which the majority of business operations are deployed around projects (Söderlund, 2005; Pemsel, Müller and Söderlund, 2016). In specific, the achievement focus, decentralization, and multidisciplinarity of projects' teams are viewed as the most significant attributes turning projects into "powerful generators" of new knowledge (Wiewiora et al., 2014). Swan, Scarbrough and Newell (2010) noted that projects as temporary entities enjoy a comparatively high level of autonomy and flexibility allowing parent organizations respond to their environment in a timelier manner.

Nevertheless, ample evidence shows that project learning is likely to be "trapped" within project boundaries (Bakker et al., 2011) exposing PBOs to "organizational amnesia" (Grabher, 2004; Ali, Musawir and Ali, 2018). That is, project characteristics, such as decentralization, goal-orientation and temporality have been closely associated with lack of project teams' motivation, opportunity and ability to share knowledge outside project boundaries (Argote, McEvily and Reagans, 2003; Bartsch, Ebers and Maurer, 2013; Eriksson and Leiringer, 2015). This in turn constitutes a "structural hole" (see Burt, 2004) impeding effective knowledge synchronization between PBOs' operational and strategic levels. Therefore, PBOs need to maintain better congruence between knowledge exploration at project level and knowledge exploitation at organizational level so that projects' knowledge contributes to organizational maturity and the latter leads to better knowledge governance at project level (Brady & Davies, 2004; Eriksson & Leiringer, 2015; Pemsel et al., 2014).

One key theoretical understanding coined in literature as an overarching concept to govern the interaction between micro and macro organizational knowledge processes is knowledge governance (KG). Foss, Husted and Michailova (2010) defines KG as the process of deciding organizational structures and procedures that in turn impact micro level processes of generating, disseminating, integrating and exploiting knowledge in pursuit of corporate-wide objectives. One of the most recognized KG structures in PBOs is the PMO, which is promoted as a middle level management between project management and top management levels (Pemsel et al., 2016) and as an enabler of organizational learning (Eriksson & Leiringer, 2015). Although PMOs can differ in their functions, a knowledge intensive PMO creates a collaborative and interactive knowledge share culture with project managers facilitating the elicitation of knowledge hard to be transferred other than direct interaction (Desouza & Evaristo, 2006). Eriksson and Leiringer (2015) show that PMOs can also serve as a strategic linkage providing higher management with key knowledge generated from projects. This in turn highlights the significance of the mediating roles played by PMO managers between project managers and top management.

In general, such intermediary roles have attracted growing research in the context of knowledge management literature. Most of these studies base their theorization on the construct of knowledge brokering. Hargadon (1998) defines knowledge brokers as the mediators, between otherwise isolated groups, benefit from their in-between position to elicit, synthesize and mobilize knowledge across the boundaries. For example, the brokering roles R&D firms' researchers to facilitate collaboration between research producers and users (Gagnon, 2011), the mediating roles of principal investigators between universities and industries to achieve commercialization goals (Kidwell, 2013), and the intermediary roles of hybrid middle level managers between different organizational levels in healthcare sector (Burgess and Currie, 2013; Currie, Burgess and Hayton, 2015).

However, only few studies focused on the knowledge brokering roles of PMOs in the context of PBOs. For example, Julian (2008) found that PMO managers not only promote inter-project exploitative learning by reusing previous projects' lessons, but also explorative learning by adopting training and mentoring endeavors. Relatedly, Pemsel and Wiewiora (2013) found that PMOs still need more capabilities to meet project managers' attitudes to share knowledge. Although these studies tried to explain how PMO managers broker particular type of knowledge flow (i.e. interproject, project-to-organization), they do not offer a holistic explanation to the determinants of potential brokering roles of PMO managers between different PBO levels. Therefore, this study tries to produce an original conceptual understanding on how PMO managers broker knowledge flow transactions within and between the three PBO levels (i.e. projects, PMO and top management). This study in part responds to Zhao, Zuo and Deng's (2015, p. 13) calls "to build consensus-based systems and shared mechanisms" to promote the governance of learning in PBOs.

The remainder of this study is organized as follows. First, we review relevant literature to introduce in-depth understanding on what turns knowledge flow in PBOs into a challenge, the practices and processes used to manage knowledge, how knowledge governance can be performed through the PMO, and PMO functions and competences needed in brokering knowledge flow at different PBO levels. Next, a comprehensive theoretical framework is synthesized to cover three distinct types of knowledge flow transactions mediated by PMO managers, namely, bottom-up, horizontal, and top-down knowledge brokering transactions. Finally, the paper is concluded with a discussion to the contributions and implications of the theoretical framework along with potential directions for future research.

2 Literature Review

This section reviews the state-of-the-art literature on knowledge management in PBOs in order to base our arguments on a firm theoretical basis. Firstly, reasons behind flawed knowledge flow in PBOs is synthesized before reviewing and categorizing most prevalent knowledge management practices and processes suggested in literature. Next, knowledge governance, as an overarching methodology to govern knowledge in PBOs through PMOs, is discussed. Finally, PMO knowledge brokering roles are discussed, and the theoretical gap is underlined.

2.1 Problematic Knowledge Flow in PBOs

Evidence on learning in PBOs is highly ambivalent (Swan et al., 2010). While there is ample evidence supporting the significant potentials of projects in producing new knowledge, equal evidence shows that projects' knowledge is likely to be "trapped" within project boundaries, however (Bakker et al., 2011). That is, knowledge flow from and between projects is found to be particularly problematic exposing PBOs to "organizational amnesia" (Grabher, 2004), where firms fall into reinventing the wheel syndrome repeating past mistakes (Pemsel & Wiewiora, 2013; Swan et al., 2010).

Extant literature attributes problematic knowledge flow in PBOs to the unique characteristics of projects as temporary organizations. That is, project characteristics are found to undermine project teams' motivation, opportunity and ability to share knowledge outside project boundaries (Argote, McEvily and Reagans, 2003; Bartsch, Ebers and Maurer, 2013). For example, the unique experience of projects has been associated with projects teams' lack of ability and motivation to identify perceived benefits to the applicability of learning outside the project (Bartsch et al., 2013). Similarly, time pressure in projects is also linked to project teams' lack of opportunity to establish social ties, with colleagues in other parts of the PBO, necessary for effective knowledge flow (Eriksson & Leiringer, 2015). Furthermore, project teams are also found to be less motivated to share knowledge owing to the absence of formal structures and incentives stemming from the transient nature of projects (Bartsch et al., 2013).

Goal-orientation is another key projects' attribute found to limit project workers' tendency to share knowledge outside project boundaries. That is, project personnel are found to be more obsessed with the delivery of work packages (Pemsel & Wiewiora, 2013) within the usually predefined projects' constraints of time, cost and quality. The extreme focus on delivery may therefore explain the so-called common practice of conducting lessons learned sessions at the end of projects (see OGC, 2017) when projects teams are not only exhausted but also face potential termination. Evidence supports the lack of value of conducting lessons learned at the end of projects as captured lessons are found to be less valuable and most of reported was about achievement rather than its underlying success elements (Newell et al., 2006).

One quite relevant challenge to cross-project learning is the potential competition over scarce resources between ongoing projects (Hansen et al., 2005). This especially the case when projects overlap in the use of tangle and intangible resources. Project teams therefore are less likely to cooperate unless parent organizations put in place effective mediating practices to bridge interproject knowledge share gap, such as knowledge governance (see Eriksson and Leiringer, 2015) and knowledge brokering (see Pemsel and Wiewiora, 2013).

In short, project attributes are two-sided. Multidisciplinarity, autonomy and achievement-orientation are key to effective intra-project knowledge generation and innovation helping parent organizations to respond to their environments in a timely manner. However, unique experience, time-bound and achievement focus have been identified as the major reasons for project personnel's lack of motivation, opportunity and ability to share knowledge outside project boundaries. Therefore, PBOs need to ensure that projects' learning is actually accumulated at organization level and that learning is thoroughly exploited both in strategy development and in the implementation of current and future projects.

2.2 Knowledge Management Practices and Processes in PBOs

In response to the substantial difficulties facing PBOs to elicit and leverage projects' knowledge, several contributions seen in literature suggesting a variety of remedies. These remedies can be positioned along a continuum ranging from systematic top-down formal practices to relational bottom-up informal processes mainly to stimulate knowledge flow from and between projects (see Figure 1). In essence, these studies build on two distinct schools of thought. On the one hand, studies treating knowledge as a more tangible commodity that can be captured, stored and retrieved apart from its context (see Hartmann and Dorée, 2015). In other words, a view tends to confuse the construct of "knowledge" with that of "information". On the other hand, research recognizing the highly tacit nature of knowledge as embedded understanding within the social and cultural contexts of projects (see Wiewiora *et al.*, 2014). That is, a perspective considering that knowledge cannot be separated from the context in which it is generated, shared, and utilized.

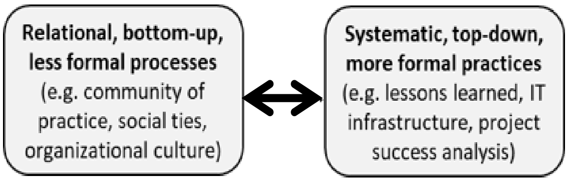

Fig. 1 Continuum of Knowledge Management Techniques

In terms of the more systematic top-down formal knowledge management practices, such as lessons learned exercise (Shokri-Ghasabeh & Chileshe, 2014), use of intranet software (Kivrak et al., 2008), and project success analysis (Todorović et al., 2015), several studies seen in literature advocating their use. Particularly, the most acknowledged technique both in practical and academia is lessons learned exercise, which is also known as "post-mortem" documentation (Julian, 2008). Lessons learned practice, which involves recapping and codifying significant project teams' experiences crucial to improve the performance of subsequent projects, is usually held at the end of projects as part of post-project reviews (see OGC, 2017). Once implemented, documented lessons are stored in firm repositories for future retrieval usually with the aid of IT infrastructure (Newell et al., 2006).

Despite the fact that the vast majority of contemporary PBOs have lessons learned policies in place, evidence shows that only few PBOs actually perform them (Keegan & Turner, 2001). Even when they are implemented, the value of gathered lessons and the transparency to what happens to them afterwards is questioned (Carrillo et al., 2013). Julian (2008) points out to the detrimental consequences of the phenomenon of "red light learning" over organizational learning where lessons learned practice is formally enforced to the extent that project personnel perceive them as punitive. Similarly, Shokri-Ghasabeh and Chileshe (2014) in a survey to construction firms in Australia, found that the most significant barriers to lessons learned practice is the lack of project teams' time, resources and clear guidelines for proper implementation.

Accordingly, the mechanistic nature of lessons learned as a formally enforced practice is found to leave less consideration to project teams social and relational context in which knowledge is basically generated, applied, and shared. This argument is supported by a range of contributions seen in literature. For example, Goffin and Koners (2011) conducted five case studies at leading German firms to uncover how NPD project personnel perceive lessons learned practice. The authors found that project teams were convinced that lesson leaned are highly depended on the context in which it is created, applied and shared and therefore less likely to be transferred "other than by direct interaction" (p. 314). Likewise, Duffield and Whitty (2014) found that lessons learned practice is less likely to succeed unless it aligns people aspects, such as culture and social ties, with system aspects, such as IT and policies.

On the other side of the continuum, the more relational bottom-up informal knowledge management processes come into existence (see Figure 1). Several scholarly investigations seen in literature scrutinizing the impact of such people-oriented processes over knowledge management and organizational learning in PBOs. In that respect, organizational culture may be considered as the most investigated process to its potential impact on how learning is framed at PBOs. In a study to a number of PBOs in Finland, Ajmal and Helo (2010) found that cultural manifestations in PBOs were crucial in defining the way in which knowledge is managed. Relatedly, Mueller (2014) identifies a range of tangible and intangible cultural artifacts as the most crucial to efficient cross-project knowledge flow.

Other studies focused on how interproject and project-organization cultural difference can be a major concern to the viable accumulation and exploitation of projects' knowledge. That is, Swan, Scarbrough and Newell (2010) show that project knowledge is less likely to be translated into institutionalized resource unless projects are deeply embedded within their organizational setting. Likewise, Hartmann and Dorée (2015) posit that cross-project learning is unlikely to occur unless it is rooted through the historical, cultural and organizational contexts of PBOs. The authors noted that "if projects are perceived as sender/receiver islands, then lessons learned remain messages in bottles—freely afloat on the ocean of knowledge, arriving at new shores by chance" (p. 10). Similarly, Wei and Miraglia (2017) argue that the alignment between projects and parent firms' organizational culture is of crucial importance to knowledge share behavior at project team level.

Other body of literature tried to identify the ideal cultural attributes for effective cross-project knowledge share. That is, Wiewiora *et al.* (2013) found that cultures characterized by evident collaboration and cooperation artifacts were more ready to share project lessons and even those unsuccessful. In a later study, Wiewiora *et al.* (2014) noted that collaborative and interactive working environment is more likely to stimulate trust, which is a crucial determinant to effective implementation of knowledge share practices. Therefore, the multifaceted nature of organizational culture received special academic focus to its potent impact over collective learning at PBOs.

Beside organizational culture, several contributions adopted more relational people-centered processes to explain how learning in project-based setting can be promoted. That is, Bartsch, Ebers and Maurer (2013) in a large scale study surveyed 218 projects in Germany found that social capital was a crucial factor in increasing project teams' motivation, opportunity and ability to share knowledge at different PBOs' levels. Other studies investigated how PBOs can learn through communities of practice (Ruuska & Vartiainen, 2005), coordination behavior (Wen & Qiang, 2016), co-creation practices (Eriksson & Leiringer, 2015), and effective communication (Yap et al., 2017).

Another body of literature argued in favor of balancing the management of both relational and systematic knowledge management practices and processes in pursuit of optimal outcomes. That is, Anand, Ward and Tatikonda (2010) conclude that both technical and social knowledge creation practices are crucial to more successful process improvement projects. Similarly, Arumugam, Antony and Kumar (2013) postulate that technical support along with social antecedents are both equally important in promoting project teams' learning potentials and in turn achieving wider organizational outcomes. Likewise, Almeida and Soares (2014) posit that there is a need to corporate-wide strategies to balance knowledge codification with personalization to overcome inherent knowledge flow difficulties seen in PBOs. Moreover, Mueller (2015) in a case study including five Austrian PBOs, the author found that project personnel use a range of formal to informal techniques in order to share knowledge across project boundaries.

Accordingly, effective PBO-wide knowledge management strategy should balance between the both ends of the continuum (see Figure 1). This means that higher management not only need to enforce formal systems and policies to manage knowledge but also to promote a collaborative and interactive organizational culture. Pemsel, Müller and Söderlund (2016) point out that corporate level knowledge management strategies should maintain effective orchestration with organizational learning processes at operational level. Thus, in order to ensure better levels of knowledge flow at PBOs, knowledge management should be seen as an ongoing process. This process needs to present feed-forward from prevailing project knowledge culture and social ties to help decision makers with providing feedback in the form of updated knowledge management strategies and so forth. In so doing, the need to overarching models and theorizations to govern knowledge flow transactions is emphasized.

2.3 KG through PMOs

Literature on holistic strategies to govern knowledge processes in organizations is still emerging. In particular, KG as one of the most recognized constructs used for this purpose, is defined by Foss, Husted and Michailova (2010) as "choosing organizational structures and mechanisms that can influence the process of using, sharing, integrating, and creating knowledge in preferred directions and toward preferred levels" (p. 456). In the context of PBOs, it is the work of Pemsel *et al.* (2014) that defines KG as "a strategic combination of knowledge processes and their enabling formal and informal mechanisms that allows moving the organization to set knowledge-based goals" (p. 9). KG therefore tries to adopt top-down formal knowledge management efforts to influence the learning behavior of project personnel. How the personnel react then provides bottom-up response to higher management embodied in the achievement of knowledge-based goals.

Pemsel, Müller and Söderlund (2016), in a large-scale study surveyed 20 project-based firms, categorize KG strategies into six distinct groups through analyzing KG characteristics at four organizational levels, namely, firm, top management, middle management and project management level. The authors then posit that effective KG strategies are highly dependent on how KG choices are made at different PBOs' levels. Later study by Pemsel, Söderlund and Wiewiora (2018) conclude that both "managements' and employees' level of readiness for learning" determine the extent to which organizational capability is developed. This study identities four distinct configurations to KG at PBOs ranging from highly interactive to highly formalistic. The ideal configuration, the authors argue, is that balances the use of both formal and informal KG mechanisms in pursuit of PBO-wide outcomes.

However, the fact that PBOs usually function at two different levels of operation, namely, project and organization (Hobday, 2000) has attracted several studies stressing the dire need to maintain effective orchestration between these two levels. This is mainly to ensure that projects' learning is actually contributing to the aggregation of knowledge at firm level, in the one hand, and that knowledge is conducive to the continuous improvement of projects' performance (Brady & Davies, 2004). Several studies seen in literature stressing not only the crucial importance of enhancing project-to-organizations knowledge flow (e.g. Swan, Scarbrough and Newell, 2010) but also but also cross-project ones (e.g. Zhao, Zuo and Deng, 2015). From this point of departure, the key roles of PMOs as middle level management in KG are underscored.

The Project Management Institute defines the PMO as "an organizational structure that standardizes the project-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques" (PMI, 2017, p. 48). In particular, PMO is a strategy developed to eliminate issues related to project planning, communication and lessons learned practice through acting as central organizational body for knowledge integration and as a repository of good practices (Desouza & Evaristo, 2006). Portfolio management office, program management office, project management center of excellence, and directorate of project management are all referring to the umbrella term of PMO (Julian, 2008).

Eriksson and Leiringer (2015) in a conceptual study investigate the extent to which PMO functions can serve as KG mechanisms. The study concludes that four out of seven recognized PMO functions are learning-oriented and can act as KG mechanisms facilitating both explorative and exploitative project learning; namely, the establishment and maintenance of lessons learned repository, development and maintenance of project management standards, training and mentoring, and strategic management. The authors therefore emphasize that PMOs are best positioned to enhance the process of reusing knowledge through introducing continuous development to project management methodologies, relevant training and consulting services, and strategic connections to project knowledge at corporate level. As such, PMOs are more capable of taking a central role in governing knowledge at PBOs.

However, PMOs can differ in their characteristics that in turn impact their capacity to govern knowledge both positively and negatively. Desouza and Evaristo (2006) in a study to the PMO division of 32 IT firms classify PMOs into four archetypes based on their capacity to manage knowledge. These archetypes categorized PMOs from wholly administrative to highly knowledge intensive, namely, the supporter, the information manager, the knowledge manager, and the coach. While the supporter roles are mainly focused on projects' reporting, the information manager provides a source of information for both project evaluation and reporting. Both of these types have almost no authority to influence projects and project success are usually related to functional departments. By contrast, the knowledge manager and the coach maintain a rich repository of best practices providing project teams with necessary mentoring and training needed to contextualize knowledge. Whereas the knowledge manager PMO has less enforcement authority to the knowledge it preserves, the coach archetype is on contrary. That is, the coach PMO acts as an enforcer of best practices and as a center of excellence to ensure continuous project improvement.

Hence, PMO as a key organizational apparatus to govern knowledge requires more detailed synthesis on the specific mix of mechanisms used to achieve better governance of PBOs' knowledge. These mechanisms need to interact in a way that promotes and motivates learning endeavors at different organizational levels (Eriksson et al., 2017). In this paper, we focus on PMO knowledge brokering behavior as an umbrella concept to other key KG mechanisms used to accomplish particular knowledge-based objectives.

2.4 Knowledge Brokering and PMOs

Knowledge brokering was originally coined in literature by Hargadon (1998) who defines knowledge brokers as the intermediaries, between otherwise isolated bodies of knowledge, benefiting from their in-betweenness state to elicit, integrate and mobilize knowledge across the boundaries. Research identifies three key functions to knowledge brokering: knowledge management, linkage and exchange, and capacity building (Chew et al., 2013; Ward et al., 2009). Knowledge management involves the elicitation, integration and mobilization of specialist knowledge to support decision making. Linkage and exchange denote the process of coordinating knowledge exchange between various bodies of knowledge especially the transactions between knowledge producers and users. Finally, capacity building involves developing the experience and expertise of the personnel through empowering them with proven knowledge and know-how. Table 1 depicts these functions along with the means needed to perform each of these functions effectively:

formation Centre staff between their company and tourists (Wong & McKercher, 2011), patient safety workers in healthcare industry (Waring et al., 2013), hybrid middle level healthcare managers at different organizational levels (Burgess and Currie, 2013; Currie, Burgess and Hayton, 2015), principal investigators between universities and industry (Kidwell, 2013), and

Table 3 Key Skills Necessary for Effective Knowledge Brokering (adapted from Kislov, Wilson and Boaden, 2017)

Knowledge Management Skills	Linkage and Exchange Skills	Capacity Building
• Searching and retrieving evidence • Appraising evidence • Synthesizing evidence • IT skills • Tailoring resources to local needs	• Mediation skills • Negotiation skills • Networking skills • Interpersonal skills • Stakeholder influencing skills	• Teaching skills • Mentoring skills • Facilitation skills • Change management skills • Improvement skills

Table 4 Key Skills Necessary for Effective Knowledge Brokering (adapted from Kislov, Wilson and Boaden, 2017)

The literature defines two key bridging strategies knowledge brokers use to mediate the relationship between brokered parties depending on the extent to which the relationship is perceived as competitive or cooperative (see Chiambaretto, Massé and Mirc, 2019). First, *tertius gaudens*, which means the third party who fills the gaps between mediated bodies (see Burt, 2004), is more appropriate when the relationship between brokered parties is competitive. In other words, knowledge brokers using this strategy is less likely to have their brokered parties in direct interactions. Second, *tertius iungens*, which denotes the third party who bridges the gaps, is more likely to be used when the relationship between the mediated parties is perceived as cooperative (see Obstfeld, 2005; Obstfeld, Borgatti and Davis, 2014). That is, knowledge brokers using this strategy facilitates the interaction and coordination between the mediated parties.

Building on the construct knowledge brokering, several studies seen in knowledge management literature trying to explain how the process of knowledge flow from, into and within organizational levels can be mediated. The vast majority of these studies were conducted in or based on generic non project-based organizational structure. For example, the brokering roles of IT professionals between different business units (Pawlowski & Robey, 2004), R&D firms' researchers between research producers and users (Gagnon, 2011; Tortoriello, Reagans and McEvily, 2011), Tourists' In-

sales workers in NPD businesses (van den Berg et al., 2014). Other studies focused on knowledge brokers as they are in independent positions. For example, knowledge brokers in healthcare industry (Chew et al., 2013; Kislov et al., 2017), comics publishing business (Boari & Riboldazzi, 2014), environmental R&D firms (Quintane & Carnabuci, 2016), and between competitive business units in video game company (Chiambaretto et al., 2019).

In comparison, only few studies focused on knowledge brokering in PBO context. Most of these contributions considered knowledge brokering roles as part of PMOs' functions as middle level management between the operational level represented by the projects and the strategic level represented by top level management (see Hobday, 2000). For example, Julian (2008) in a qualitative study interviewed 20 PMO managers to investigate their mediating roles in promoting cross project learning. The author found that PMO leaders not only broker knowledge retrospectively in the form of reporting and lessons learned practices but also prospectively in the form of mentoring, training, and developing standards and methodologies. Relatedly, Pemsel and Wiewiora (2013) in a multiple case study research interviewed 64 project managers from seven different PBOs. The study found that PMOs as knowledge brokers still require more capabilities to meet project managers' knowledge share attitudes. Therefore, there is an evident practical mismatch between PMOs knowledge brokering efforts and project managers' knowledge sharing behavior calling for more interactive theoretical explanations.

What is lacking, therefore, is a detailed theoretical understanding on how PMOs' managers need to broker different management levels within PBOs for more effective knowledge-laden goals accomplishment. Chiambaretto, Massé and Mirc (2019) argue that we not only need to understand the behavior of those in brokering roles, but also how the brokering transactions are performed more concretely. Indeed, extant literature on PMO knowledge brokering roles offers only scant explanation and this conceptual study therefore is taking the opportunity to integrate evidence from other disciplines, such as healthcare and R&D studies, to provide more in-depth synthesis on how knowledge flow transactions at different PBO levels can be brokered by PMO managers.

3 Theoretical Framework: PMOs' Knowledge Brokering Roles and Knowledge Flow Transactions

PMO as a middle level management between operational level, represented by projects, and strategic level, represented by top level management, has been widely recognized as an intermediary entity facilitating knowledge flow transactions at different PBOs' levels (Julian, 2008; Pemsel & Wiewiora, 2013). Apart from its crucial role in developing and maintaining proven techniques and methodologies, PMO can actively contribute to strategy development process and constantly provide projects' personnel with required training and mentoring (Eriksson & Leiringer, 2015). Therefore, in-depth synthesis to the potential PMO knowledge brokering roles, in mediating knowledge flow transactions at different PBO level, is needed. Building on Gould and Fernandez's (1989) brokerage typology and its extension by Shi, Markoczy and Dess (2009), PMO managers mediate knowledge flow at PBOs using three key types of brokering transaction:

3.1 Bottom-up Knowledge Brokering Transactions

This includes three types of transactions (see figure 2). First, project level to PMO level then to top management level knowledge flow. Since PMO managers mediate this transaction between two independent bodies of knowledge, liaison is the term used to describe PMO managers performing this role (see Gould and Fernandez, 1989). Second, project level to PMO level transaction where PMO managers broker knowledge flow between projects as an outsider and their PMO team as an insider. This type of brokering is usually termed as gatekeeping (see Gould and Fernandez, 1989). Finally, the transaction originating from PMO level to top management level. In this transaction PMO managers benefit from their in-group colleagues before brokering knowledge up to top management level. This type of brokers is widely known as representatives (see Gould and Fernandez, 1989). Each of these three brokering roles to be discussed with more in-depth synthesis as follow:

3.1.1 Bottom-up Liaison

This brokering role involves PMO managers linking project managers with top managers through mediating a bottom-up knowledge flow process. Such PMO managers therefore try to elicit, validate and integrate projects' knowledge motivated by the goal of championing strategic alternatives to top managers (see Hobbs and Aubry, 2007; Shi, Markoczy and Dess, 2009). This brokering archetype is especially relevant to the process of prospective learning since project level knowledge is mobilized as a feedforward up to decision-making level (Julian, 2008).

However, knowledge flow from projects has long been found to be problematic (Swan et al., 2010; Zhao et al., 2015). That is, project managers are less likely to share knowledge in effective manner unless PMO managers adopt more relational boundary encounters, such as informal meetings, coffee breaks, and interactive communications to elicit projects' knowledge (Pemsel & Wiewiora, 2013; Star & Griesemer, 1989). This requires PMO managers to have significant linkage and exchange capabilities in terms of interpersonal and networking skills (see table 1). Therefore, should PMO managers be successful in their knowledge brokering role, they need to "create collaborative communities for project managers to share knowledge and learning that may be difficult to capture and document through conventional mechanisms" (Desouza and Evaristo, 2006, p. 422). In so doing, the visionary mismatch between project managers, who are more obsessed with the realization of projects' goals, and PMO managers, who have more program/portfolio level objectives, is more likely to be alleviated.

Similarly, interpersonal and networking skills are also crucial in promoting top managers confidence in the strategies proposed by PMO managers acting this role (see Shi, Markoczy and Dess, 2009). In addition, such PMO managers should own a particular set of knowledge management skills necessary to the success of championing strategic alternatives before higher management bodies. In specific, knowledge evaluation, integration and articulation skills are needed to tailor gathered projects' knowledge to the needs of top managers (see table 1). Moreover, since liaison role involves mediating two different bodies of knowledge, the experience of such in-betweenness has been associated with role ambiguity and role conflict (Stamper & Johlke, 2003) where knowledge brokers can be lost in the "in-between world" (Kislov et al., 2017, p. 4). Accordingly, there is a crucial need to specific type of skills, Borg and Söderlund (2015) term as "liminality competence", in the face of the role tensions experienced during such in-between operations.

In terms of the bridging strategy, since project managers are not structurally equivalent to PMO managers, bottom-up liaisons are expected to follow *tertius iungens* strategy (see Obstfeld, Borgatti and Davis, 2014). In this strategy PMO managers tend to allow direct interactions between project managers and top

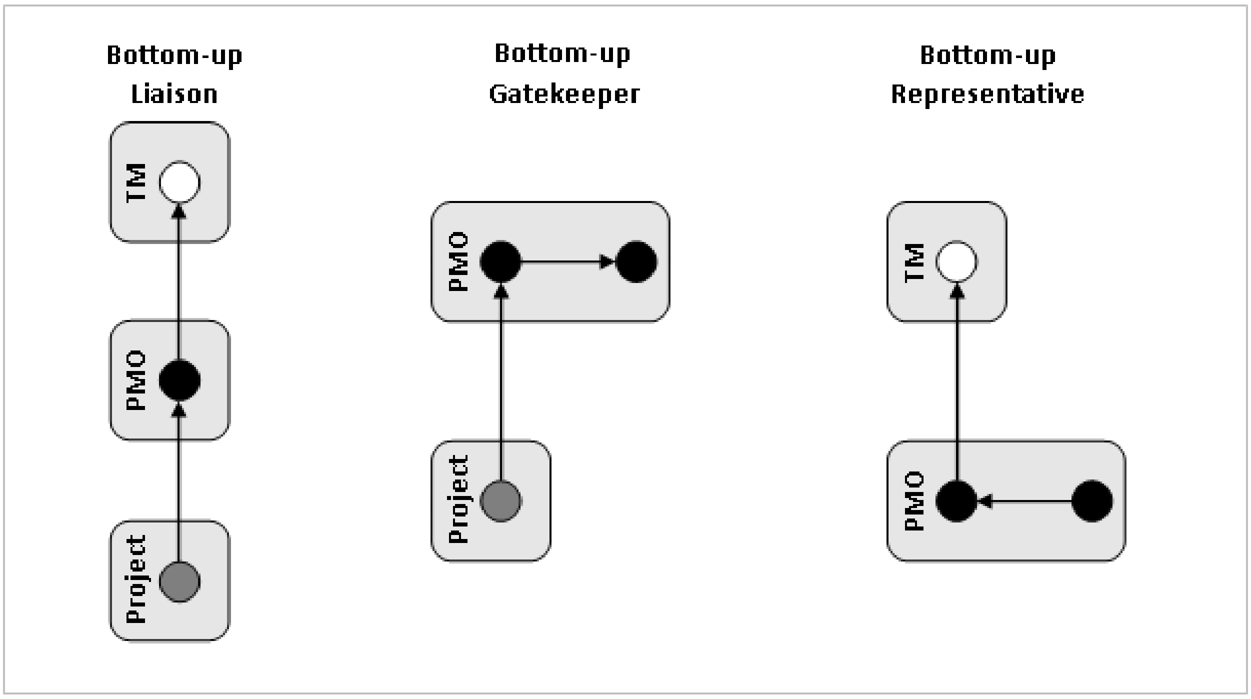

Fig. 2 Graphical Representations to Bottom-up Knowledge Brokering Transactions (Note: Top manager is abbreviated as TM)

managers when required. This strategy is especially important to motivate lower level managers to share knowledge by allowing them participate in the process of championing initiatives to higher management level (Westley, 1990; Shi, Markoczy and Dess, 2009).

3.1.2 Bottom-up Gatekeeper

This brokering role denotes the bottom-up knowledge flow transaction manipulated by focal PMO managers between project managers and PMO team. That is, this role involves synthesizing projects' knowledge before filtering out the most promising aspects to peer PMO managers for feedback (see Gould and Fernandez, 1989; Shi, Markoczy and Dess, 2009). As such, bottom-up gatekeeper plays a key role in building PMO knowledge base crucial to develop strategic alternatives to higher management and provide continuous support to projects. Therefore, this brokering archetype is more involved in the process of prospective learning by promoting knowledge integration and accumulation for future need (Julian, 2008).

Since project managers are more “passionate” about their projects (Pemsel and Wiewiora, 2013), focal PMO managers need to use more coincident boundary objects in their operations with project managers, such as informal meetings and interactive communications (Pemsel & Wiewiora, 2013; Star & Griesemer, 1989). This is to ensure better knowledge elicitation by meeting project managers knowledge sharing behavior. Focal PMO managers therefore need to develop their linkage and exchange skills especially in networking and interpersonal influence (see table 1). In addition, PMO managers should also be competent in their knowledge management function in order to ensure better quality manipulation to the knowledge coming in from projects. In particular, in terms of developing their knowledge evaluation, integration and tailoring skills (see table 1). However, this brokering role does not need to have significant liminality competence since it is partially dealing with outsiders (see Borg and Söderlund, 2015). In other words, between their peer group in PMO and project managers as outsiders.

Bottom-up gatekeepers are expected to follow *tertius gaudens* as a bridging strategy since their major function is to control the quality and quantity of knowledge inflow to PMO group (see Shi, Markoczy and Dess, 2009). That is, such PMO managers act as a shield filtering out promising knowledge to the process of championing initiatives. Therefore, they are less likely to allow peer PMO managers to take over this privilege.

3.1.3 Bottom-up Representative

This role involves the bottom-up knowledge flow transaction originated from the PMO up to top management level and mediated by a focal PMO manager. That is, PMO team works to validate, integrate and communicate strategies to a focal PMO manager who represents the group interests in the process of championing strategic alternatives. The major objective of bottom-up representative is to build a powerful communication platform not only to champion initiatives but also to keep top management informed (see Shi, Markoczy and Dess, 2009). Since this role is generally involved with suggesting new insights to top management, it is more oriented towards prospective than retrospective learning, trying to generate new standards for future use (see Julian, 2008).

PMO managers, as any middle level managers at this brokering archetype, perform two key functions of initiative championing and status reporting (see Shi, Markoczy and Dess, 2009). Each of these functions requires a different boundary technique. On the one hand, championing initiatives requires more interactive boundary techniques (e.g. informal meetings and communication) in order to promote higher management confidence in the proposed strategies. This entails focal PMO managers to have superior networking and interpersonal skills to perform their linkage and exchange function more successfully (see table 1). On the other hand, status reporting requires more systematic boundary techniques (e.g. reports writing, emails updates, and formal meetings) in order to keep higher management informed. The latter techniques require focal PMO managers to have IT and knowledge synthesis skills in order to perform their knowledge management function more effectively (see table 1). Like bottom-up gatekeepers, this brokering role does not require focal PMO managers to have significant liminality competence as they broker their group interaction with top managers as outsiders (see Borg and Söderlund, 2015).

Bottom-up representative is expected follow *tertius iungens* as a bridging strategy in order to allow top management access to the origins of initiative when required. This is mainly to promote top management confidence in the initiatives by ensuring that they are subject to collective verification (see Shi, Markoczy and Dess, 2009). As such, bottom-up representatives are likely to close the gap between peer PMO managers and top management especially when top management requires more confidence to approve or proceed with a new strategy.

3.2 Horizontal Knowledge Brokering Transactions

This includes three types of transactions (see figure 3). First, cross-project knowledge flow where PMO managers broker the transactions between two independent projects. This type of brokers is usually known as liaison (see Gould and Fernandez, 1989). Second, intra-project knowledge flow interventions where PMO managers broker particular transactions within project boundaries. Brokers mediating knowledge flow transactions between intra-group outsiders are known as cosmopolitans (see Gould and Fernandez, 1989). Finally, PMO managers mediating roles within the PMO per sue. This type of brokers is known as coordinators (see Gould and Fernandez, 1989). Each of these three brokering roles to be discussed with more detailed synthesis as follows:

3.2.1 Horizontal Liaison

This brokering role involves PMO managers linking project managers operating at different projects through facilitating horizontal cross-project knowledge flow process. PMO managers thereby seek to elicit and assess projects' knowledge with an intention of reusing it in other ongoing projects. However, sometimes PMO managers may transfer specific knowledge to other projects with a goal of verifying the viability of that knowledge before suggesting it as a strategic initiative before top managers (see Shi, Markoczy and Dess, 2009). Horizontal liaison operations involve prospective learning since fresh projects' knowledge is mobilized to be used in other ongoing projects (see Julian, 2008).

Since knowledge flow from projects is inherently problematic (see Swan, Scarbrough and Newell, 2010; Zhao, Zuo and Deng, 2015), PMO managers may require more social impact over project managers knowledge sharing attitudes. This can be achieved through boundary encounters processes, such as interactive and collaborative meetings and communications (Pemsel & Wiewiora, 2013; Star & Griesemer, 1989). Therefore, horizontal liaisons need to have more interpersonal and networking competence in their linkage and exchange operations with project managers (see table 1). In addition, moving back and forth between projects usually requires more linkage and exchange skills in terms of mediation and negotiation (see table 1).

In order to have more effective cross-project knowledge share transactions, PMO managers in this role need to develop their knowledge management skills necessary to evaluate and communicate knowledge (see table 1). In addition, operating between two independent bodies of knowledge is expected to

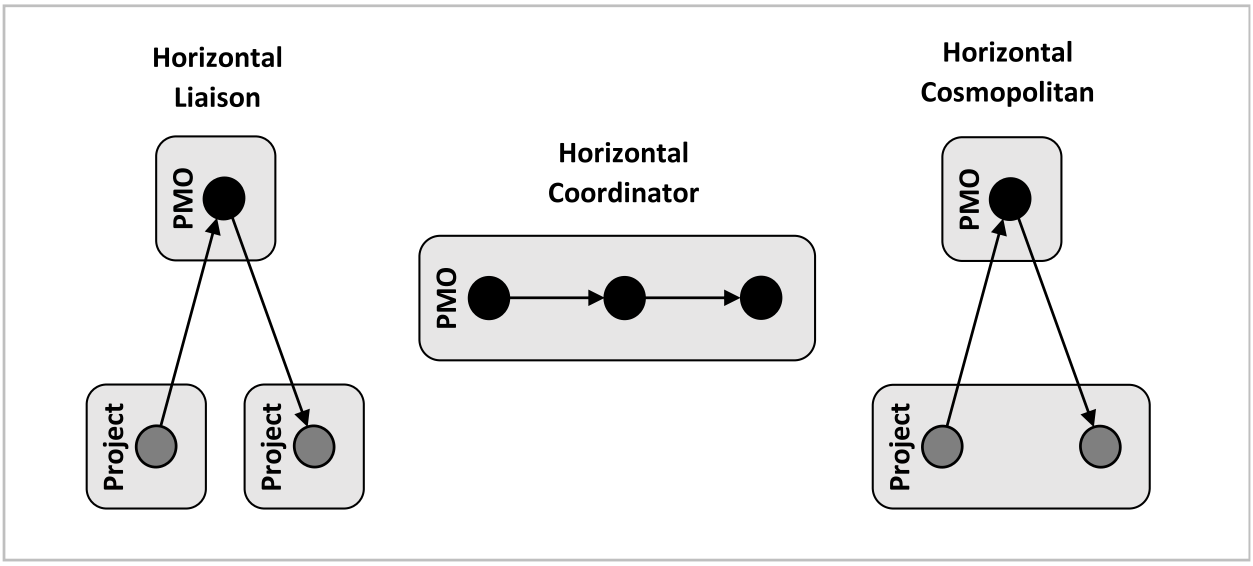

Fig. 3 Graphical Representations to Horizontal Knowledge Brokering Transactions

leave focal PMO managers with role ambiguity and role conflict (see Stamper and Johlke, 2003). As a result, PMO managers need to develop their liminality competence to ease such role tensions (see Borg and Söderlund, 2015).

In terms of the bridging strategy, whether horizonal liaisons adopt *tertius iungens* or *tertius gaudens* is somewhat dependent on the extent to which the relationship between mediated projects is perceived as competitive versus cooperative (see Hansen, Mors and Løvås, 2005; Chiambaretto, Massé and Mirc, 2019). However, competition may be more likely as project managers are more concerned about the achievement of their projects' objectives (see Pemsel and Wiewiora, 2013). This in turn gives more likelihood to *tertius gaudens* as a bridging strategy.

3.2.2 Horizontal Cosmopolitan

This role denotes PMO managers' interventions to facilitate intra-project knowledge flow when required. Julian (2008) holds that PMO leaders not only broker knowledge flow from and into projects, but also within the projects. This is especially the case when PMO managers, as middle level managers, monitor the implementation of a new strategy or emerging know-how (see Shi, Markoczy and Dess, 2009). This includes mediating knowledge flow between project managers and other project bodies, such as team managers and project support. Learning orientation of this brokering role can be both prospective and retrospective, as it involves monitoring the application of knowledge extracted from previous experience as well as monitoring the emergence of new knowledge (see Julian, 2008).

The operations of this brokering archetype require more interactive boundary techniques in order to closely monitor the implementation of a new strategy (see Star and Griesemer, 1989; Pemsel and Wiewiora, 2013). As a result, focal PMO managers need to develop their skills in teaching and mentoring as part of their capacity building function (see Eriksson and Leiringer, 2015). In addition, relational boundary techniques by their very nature require those in such brokering roles to have superior networking and interpersonal skills as part of their linkage and exchange function (see table 1). Finally, role ambiguity and role tensions are more likely due to the fact that focal PMO managers in such roles are mediating the interactions between outsiders (see Borg and Söderlund, 2015). The bridging strategy that is more likely to be used by horizontal cosmopolitans is *tertius iungens*. This is because of the main objective of this brokering role in reaching a consensus over the implementation of new strategy or know-how.

3.2.3 Horizontal Coordinator

This brokering role involves PMO managers facilitating internal transactions with their peer group within the PMO. The main objective of horizontal coordinator is to ensure that emerging strategic initiatives are thoroughly debated within the PMO before championing it before top managers (see Shi, Markoczy and Dess, 2009) through bottom-up representative role. Since this role is more involved with the process of developing new strategic initiatives, its learning orientation is more prospective aim at exploit knowledge for future use (see Julian, 2008).

Since the transactions of this brokering role are completely internal, the need for more relational boundary techniques, such as informal communication and meetings, may be of crucial importance (see Star and Griesemer, 1989; Pemsel and Wiewiora, 2013). As such, networking and interpersonal skills are key for more effective linkage and exchange function to focal PMO managers (see table 1). Moreover, operating in the heart of the process of developing strategic alternatives may also means that horizontal coordinators need to develop their knowledge evaluation and integration skills (see table 1). Finally, internal transactions may also mean that focal PMO managers prefer to adopt *tertius iungens* (i.e. bridging the gap between mediated parties) as a bridging strategy. Adopting this strategy not only boosts the speed of communication, but also add to the quality of debate and in turn the output initiatives (Shi, Markoczy and Dess, 2009).

3.3 Top-down Knowledge Brokering Transactions

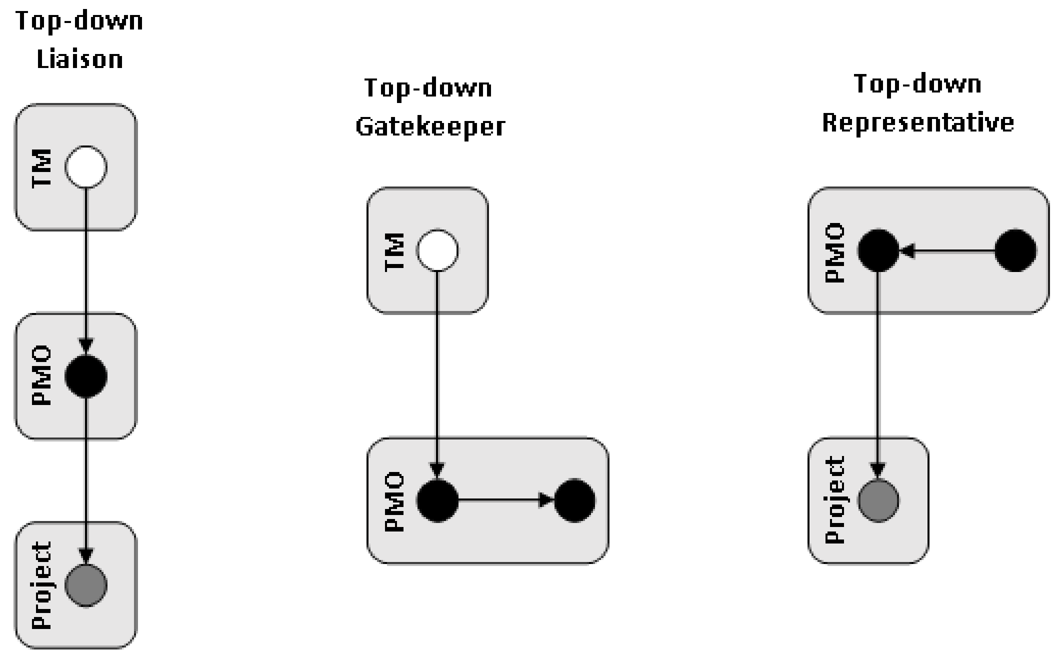

Fig. 4 Graphical Representations to Top-down Knowledge Brokering Transactions

This type of transactions can be classified into three distinct categorizes (see figure 4). First, top management level down to project level knowledge flow transaction mediated by a focal PMO manager. This type of brokering role is known as liaison as the focal PMO manager needs to mediate the transaction between two outsiders from two different groups (see Gould and Fernandez, 1989). Second, top management level to PMO level transaction mediated by a focal PMO manager. Since such focal PMO managers control top management knowledge flow to their PMO team, they can be recognized as gatekeeps (see Gould and Fernandez, 1989). Finally, PMO level down to project level knowledge flow transaction brokered by a focal PMO manager. The latter role is known as representative since such brokers represent their group interest before another group (see Gould and Fernandez, 1989).

3.3.1 Top-down Liaison

This brokering role involves PMO managers mediating knowledge flow transactions between top management and project level. The main objective behind this type brokering roles is to facilitate the process of strategy implementation (Shi, Markoczy and Dess, 2009). As such, corporate strategy imposed by top level management is cascaded down to project level by focal PMO managers. Since strategy enforcement often originates from former projects' experience to support the implementation of current projects, learning orientation associated with this brokering archetype is then more retrospective (see Julian, 2008).

This type of brokering requires both relational as well as systematic boundary techniques in communicating new strategy to project level (Pemsel & Wiewiora, 2013; Star & Griesemer, 1989). On the one hand, explicit know-how, which the project team can readily master or acquire (Goffin & Koners, 2011; Polanyi, 1966), can be sent through written plans. This means that focal PMO managers need to have better competence in terms of IT and tailoring skills in order to effectively communicate the new strategies at project level. On the other hand, tacit knowledge that is difficult to shared rather than direct interaction (Goffin & Koners, 2011; Polanyi, 1966). This entails PMO managers acting such roles to have superior interpersonal, networking, mentoring, and teaching skills to communicate imposed strategy in more effective and interactive manners (see table 1). In addition, operating between two independent external groups means that top-down liaisons need to develop their mediation and negotiation skills as part of their linkage and exchange function. Likewise, liminality competence is more important to focal PMO managers to mitigate role tensions (Kislov, Wilson and Boaden, 2017) stemming from the fact of brokering two external bodies of knowledge (see Borg and Söderlund, 2015). The bridging strategy used by top-down liaisons is more likely to be *tertius iungens* in order to promote top managers' confidence through allowing them to closely monitor strategy implementation.

3.3.2 Top-down Gatekeeper

This brokering role denotes the top-down knowledge flow transaction manipulated by focal PMO managers between top managers and PMO team. This role acts as a shield against immature and developing strategies imposed by top managers (Shi, Markoczy and Dess, 2009). In this way, focal PMO managers are expected to filter out the most promising aspects to their peers in PMO team to be translated and tailored to facilitate delegation and implementation at project level. Learning orientation of this brokering archetype is therefore more retrospective than prospective since it involves top-down strategy enforcement that is usually informed by past project experience (see Julian, 2008).

Top-down gatekeepers are more likely to adopt more systematic boundary techniques in their gatekeeping role (see Star and Griesemer, 1989; Pemsel and Wiewiora, 2013). This entails focal PMO managers to have significant knowledge evaluation skills to filter out the most promising strategy aspects to be transferred to their peers in PMO team (see table 1). In addition, this brokering archetype is less prone to role tensions since it is not solely dealing with outsiders meaning that owning liminality competence is not essential for effective performance of such PMO managers (see Borg and Söderlund, 2015).

In terms of the bridging strategy, focal PMO managers acting this role is more likely to follow *tertius gaudens*. This is mainly to shield some top managers' emergent and developing strategies expected from affecting ongoing PMO efforts to suggest strategic alternatives (Shi, Markoczy and Dess, 2009). In this way, better levels of strategic flexibility can be maintained through governing the interaction between strategy development and enforcement of PMO team and top managers respectively.

3.3.3 Top-down Representative

This brokering role involves the top-down knowledge flow transaction mediated by focal PMO managers between PMO team and project managers. Such brokering role is pivotal not only to PMO function in strategy translation (Hobbs & Aubry, 2007), but also in retrieving PBO repositories to provide projects with required training and mentoring (see Julian, 2008; Eriksson and Leiringer, 2015). Thus, learning orientation of this brokering role is more retrospective since it involves using previous knowledge (see Julian, 2008).

Top-down representative is more likely to use more relational boundary techniques, such as informal meetings and communications (Pemsel & Wiewiora, 2013; Star & Griesemer, 1989). This means that such PMO managers requires more interpersonal and networking skills (see table 1) not only to stimulate their peers' knowledge share behavior, but also project managers readiness to apply that knowledge. This in turn requires focal PMO managers to have better training and mentoring skills as part of their capacity building function (see Eriksson and Leiringer, 2015). Another key knowledge management skill needed for effective knowledge transmission as part of representative brokering is IT skills (see table 1). However, this brokering archetype does not require having significant liminality skills since its transactions are not wholly external (see Borg and Söderlund, 2015).

Unlike gatekeeper archetype, representative brokers are more focused on enhancing the quality of information flow rather than its control (Gould & Fernandez, 1989; Shi et al., 2009). This means that focal PMO managers acting this role is more likely to follow *tertius iungens* as a bridging strategy. Hence, direct interactions between peer PMO managers and project managers are accessible when required.

4 Discussion

Extant literature on PMO knowledge brokering roles does not offer in-depth synthesis to the determinants of each brokering role in mediating various knowledge flow transactions. Building on Gould and Fernandez's (1989) brokering typology and its extension by Shi, Markoczy and Dess (2009),, we identify three key categories of knowledge flow transactions each of which is mediated by three distinct archetypes of knowledge brokering roles. First, bottom-up transactions from lower to higher power bodies of knowledge. This includes the flow of knowledge coming from projects up to PMO and top management levels. Second, horizontal knowledge flow transactions within and between same level bodies of knowledge. This includes inter-project, intra-project and intra-PMO knowledge flow transactions. Finally, top-down transactions from higher to lower-level bodies of knowledge. This includes knowledge flow from higher management down to PMO and project levels. Our study is unique in defining all potential knowledge brokering roles the PMO act to enhance PBOs' knowledge exploration, exploitation, and synchronization.

The categorization presented in this study highlights a number of theoretical findings. At bottom-up knowledge brokering level, it has been found that PMOs' knowledge brokering roles significantly contribute to the process of prospective learning through ensuring that projects' knowledge is elicited, evaluated and integrated to inform decision making at higher management level. This can clearly be seen in the strategic determinants of this type of knowledge flow transactions where PMO managers acting as gatekeepers work to establish a firm PMO knowledge base.

Table 2 Summary of the Theoretical Framework

Brokering Archetype	Mediated Parties	Strategic Objectives	Learning Orientation	Operational Techniques	Required Competence	Bridging Strategy
Bottom-up Knowledge Brokering Transactions						
Bottom-up Liaison	Projects and Top Management	Championing strategic alternatives	Prospective	Relational (e.g. interactive meetings and communication)	Interpersonal, networking, evaluation, integration and liminality	Tertius iungens (close the gap)
Bottom-up Gatekeeper	Projects and PMO	Building knowledge base	Prospective	Relational (e.g. interactive meetings and communication)	Interpersonal, networking, evaluation and integration	Tertius gaudens (fill the gap)
Bottom-up Representative	PMO and Top Management	Build a powerful platform to champion initiatives and report on projects' performance	Prospective	Relational & systematic	Interpersonal, networking, IT, integration	Tertius gaudens (fill the gap)
Horizontal Knowledge Brokering Transactions						
Brokering Archetype	**Mediated Parties**	**Strategic Objectives**	**Learning Orientation**	**Operational Techniques**	**Required Competence**	**Bridging Strategy**
Horizontal Liaison	Inter-project	Verify or develop projects' knowledge	Prospective	Relational (e.g. interactive meetings and communication)	Interpersonal, networking, evaluation, integration, mediation, negotiation and liminality	Tertius gaudens (fill the gap)
Horizontal Cosmopolitan	Intra-project	Monitoring strategy implementation and knowledge emergence	Prospective & Retrospective	Relational (e.g. interactive meetings and communication)	Teaching, mentoring, networking, interpersonal, and liminality	Tertius iungens (close the gap)
Horizontal Coordinator	Intra-PMO	Knowledge integration	Prospective	Relational (e.g. interactive meetings and communication)	Interpersonal, networking, evaluation, and integration	Tertius iungens (close the gap)
Top-down Knowledge Brokering Transactions						
Brokering Archetype	**Mediated Parties**	**Strategic Objectives**	**Learning Orientation**	**Operational Techniques**	**Required Competence**	**Bridging Strategy**
Top-down Liaison	Top Management and Projects	Strategy implementation	Retrospective	Relational & systematic	Interpersonal, networking, IT, tailoring, teaching, mentoring, mediation, negotiation, liminality	Tertius iungens (close the gap)
Top-down Gatekeeper	Top Management and PMO	Shield immature strategies, strategy translation	Retrospective	Relational & systematic	Interpersonal, networking, IT, and tailoring,	Tertius iungens (close the gap)
Top-down Representative	PMO and Projects	Training and mentoring	Retrospective	Relational (e.g. interactive meetings and communication)	Interpersonal, networking, teaching, mentoring, and IT	Tertius iungens (close the gap)

This constitutes a platform from which PMO managers acting as representatives to champion strategic alternatives before higher management (see table 2). This is also evident in bottom-up liaison role whereby focal PMO managers directly leverage projects' knowledge in championing initiatives process. Another key finding at this level denotes the specific individual qualities necessary to focal PMO managers to perform their knowledge brokering roles in an effective manner. This includes interpersonal and networking skills crucial to PMO managers acting as gatekeepers and liaisons to elicit knowledge from project managers, who are more obsessed with the achievement of their projects than sharing knowledge (see Pemsel and Wiewiora, 2013). In addition, knowledge evaluation and integration skills necessary for PMO managers acting as gatekeepers and liaisons in their efforts to develop new strategic initiatives (see table 2).

At horizontal knowledge brokering level, it has been noticed that prospective learning was generally supported. That is, PMO managers acting these roles have been found to be more focused on developing and integrating projects knowledge. In terms of the personal characteristics, role tensions were expected to be experienced by PMO managers acting as liaisons and cosmopolitans due to their totally external transactions (see Stamper and Johlke, 2003). This highlights Borg and Söderlund's (2015) call to acquire liminality competence in the face of role ambiguity and role conflict resulted from dealing with outsiders (see table 2).

At top-down knowledge brokering level, it has been found that PMOs' knowledge brokering roles contribute to the process of retrospective learning through retrieving and adapting previous projects' knowledge to facilitate the accomplishment of PBO-wide objectives through projects. This can clearly be seen in the strategic determinants of PMO managers acting as representatives, who try to ensure that previous projects' lessons are adapted to the needs of ongoing projects (see table 2). Similarly, PMO managers acting as liaisons and gatekeepers participate to the process of strategy implementation that in essence represents a form of exploitative learning (see Brady and Davies, 2004; Eriksson and Leiringer, 2015). Another key finding at this level involves the personal attributes PMO managers need to own to effectively perform top-down knowledge brokering roles. This comprises teaching and mentoring skills key to PMO managers acting as liaisons and representatives to help project teams to implement enforced strategies and adapt previous knowledge (see table 2).

In general, all of the nine knowledge brokering roles identified at this study required more relational boundary techniques to perform knowledge flow transactions in an effective manner. This highlights the tacit nature of knowledge that in most cases cannot be transferred rather than direct interaction (see Desouza and Evaristo, 2006). This finding is in line with previous contributions advocating the use of more interactive operational techniques to effectively elicit projects' knowledge (e.g. Wiewiora *et al.*, 2014; Hartmann and Dorée, 2015). This finding is significantly reflected in the individual attributes PMO managers need to have to perform the knowledge brokering role in an effective manner. That is, in all of the introduced roles, interpersonal and networking skills were highly crucial specially to stimulate project managers knowledge sharing behavior (see table 2).

5 Conclusions

The aim of this paper was to introduce a theoretical understanding on how PMO managers broker knowledge flow transactions within and between the three PBO levels (i.e. projects, PMO and top management). Following a literature-based methodology, a theoretical framework has been developed identifying strategic, operational, individual and structural determinants of each knowledge brokering role played by PMO managers at three different levels of knowledge brokering transactions (see table 2).

This theoretical model in turn stimulates a number of key conclusions. First, PMOs' knowledge brokering function has powerful potentials to effectively govern PBOs' knowledge by balancing bottom-up explorative knowledge flow with top-down exploitative knowledge flow. In other words, providing higher management with continuous feedforward to inform decision making that in turn reacts in more enhanced feedback in the form of new strategies. This is especially key to provide a fertile ground to innovation where the ideas and perspectives of those at operational levels are encouraged though proper elicitation, mobilization, and exploitation. In so doing, the proposed network of knowledge brokering roles plays a crucial role maintaining continuous organizational improvement iteratively and continuously.

Secondly, knowledge brokering is a multifaceted construct that cannot be predicted without defining the direction of knowledge flow and the characteristics of mediated entities. This highlights the widespread oversimplification seen in previous studies in treating knowledge brokering roles as a single-faceted construct. In this way, each knowledge brokering role played by PMO managers has been defined with a specific set of determinants necessary for more optimal levels of knowledge brokering performance at PBOs.

This study contributes to the literature of knowledge management in the context of PBOs by presenting a conceptual model to the network of knowledge brokering roles played by PMO managers. This model presents in-depth synthesis on how each knowledge flow transaction needs to be mediated by PMO managers. Prior research has, however, considered PMO knowledge brokering functions as a single-faceted construct. This paper also contributes to PMO literature by explaining and emphasizing PMOs' knowledge brokering roles necessary to perform each knowledge flow transaction.

There are also practical implications to the theoretical framework developed in this study. First, PBOs need to understand the dynamism behind PMO knowledge brokering roles in terms of knowledge flow direction and the characteristics of mediated parties. This in turn helps organizations to plan necessary actions to enhance knowledge exploration and exploitation necessary to their growth and maturity. Second, identifying the most needed individual attributes to every knowledge brokering role is key to PBOs to have better quality and quality skills needed at PMO divisions. That is, human resources management in PBOs is expected to have more informed decisions in hiring, delegating and upskilling PMO managers.

However, some limitations do appear in this research. That is, this conceptual study was based on previous theoretical models and evidence that are not solely developed or conducted in project-based setting. This is mainly attributed to the scant literature published on PMOs' knowledge brokering roles. Therefore, future research needs to closely observe knowledge brokering roles of PMO managers and precisely identify the determinants of performing each role in more effective manner. In addition, conceptual studies do not offer hypothesis testing which means that future studies need to examine the emerging elements of the theoretical model.

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Innovation Success Recipes Configuration to Apparel Industry: Evidence from Apparel Manufacturing Multinational Firms Operating in Ethiopia

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Abstract

This study ultimately aspires to examine how different innovation capability components can be configured to give high innovative performance in the context of apparel industry. Since apparel industries need specific innovation capabilities due its time-sensitive nature to ensure their sustainable competitiveness, innovative capability configuration is thus a hub to boost up its competitiveness. To this end, this study has considered 17 apparel manufacturing multinational firms operating in Ethiopia to configure the innovation capabilities of the industries. Hence, the study has obtained five factors through principal component analysis (PCA) method. In so doing, through fuzzy set qualitative comparative analysis (fsQCA), the five factors have been configured towards best recipes that enable apparel firm's innovation performance in ensuring their sustainable competitiveness. Finally, three alternative solutions are revealed that could bring high innovation performance in apparel industry. To this effect, improvisational and transactional capabilities are believed to be found in all three alternative solutions. Eventually, the findings of this study are expected to have paramount contribution to the ongoing literature in a way that sustainable competitiveness schemes for apparel industries are needed to build innovation capabilities, whereas improvisational capability is essential to stabilize in the dynamic and ever changing global market.

Keywords: fsQCA, low-tech firms, innovation capabilities, success recipe

1 Introduction

As uncertainty and change are major features of today's business scenario, innovation is thus a vital strategic weapon to combat challenges imposed by the environment. Firms need to build its innovation performance to ensure sustainable competitiveness. In this regard, firm level innovation studies so far acknowledged two perspectives: innovation as research and development (R&D) born and a result of different innovation capabilities(Ruffoni et.al., 2018). Regarding the first perspective, there is a misconception in understanding innovation and R&D(Arundel et.al., 2007). This confusion might thus lead to the conception so far that prioritizes R&D to get the main emphasis of developmental and policymaking research in the field of innovation(Huang et.al, 2010). In practice, R&D is neither a necessary nor a sufficient condition for innovation(Barge-Gil et.al., 2011). In this respect, a surprising evidence identified by Arundel et.al., (2007) asserts that almost half of manufacturing firms across Europe do not perform R&D but they are still innovative.

Concerning the second approach, innovation performance comes as a function of different innovation capabilities. Richardson (1972) defined innovation capability as "firm's accumulation of knowledge, experience and skills, which will be responsible for the acquisition of competitive advantages." Regarding low-tech firms, their innovative performance comes from their specific innovation capabilities

(Reichert et.al., 2016). Several recent studies suggested a set of capabilities: operational capability (OC) (Zawislak, Padula, et.al., 2012), transaction capability (TC) (Zawislak, Alves, et.al., 2012), developmental capability (DC) (Zawislak, Alves, et.al., 2012), management capability (MC) (Zawislak, Alves, et.al., 2012), improvisation capability (IC) (Cao, 2013; L. Kung, 2015; L. A. Kung & Kung, 2019; Wang, n.d.).

Among the aforementioned studies, only Reichert et.al., (2016) used Zawislak's et.al., (2013) four dimension innovation capabilities to explore and suggest success recipes of high innovation performance in Brazilian low-tech industries. They confirm that innovation performance of a firm cannot be attained via a single competence. Whereas, for low-tech industries innovation capability, they formulated a success recipes by configuring innovation capabilities using 24 items: developmental capability (6 items), operations capability (6 items), management capability (7 items), and transaction capability (5 items) by using Brazilian industry data for years from 2010-2014. In so doing, though they have attempted to reduce heterogeneity problem by excluding 17 firms having employee number more than 500, heterogeneity to the sector specificity within the low-tech industries arises. Consequently, it can be deduced that it is due to heterogeneity problem that Pavitt's (1984) taxonomy of industries was criticized by scholars in the regard.

In this study, it has been aimed to understand the causal relationships between important aspects of apparel firms' innovation capabilities with their innovation performance. In order to find out causal conditions, more importantly configurations of causal conditions, and how these conditions contribute to innovation performance of apparel firms, the PCA (principal component analysis) and fsQCA (fuzzy set qualitative comparative analysis) have been employed. To this end, information gathered from 17-apparel manufacturing multinational firms (all are 100% export oriented and working in industrial park) were used. From this study analysis, it has been identified three possible configuration of improvisational, developmental, operational, management, and transaction capabilities that can lead apparel firms to achieve high innovative performance. Hence, from all the three alternative configurations, improvisational and transactional capabilities are identified as core elements. This study finding contribute to the ongoing literature in a way that sustainable competitiveness schemes for apparel industries are needed to build improvisational capabilities to stabilize in the dynamic and ever-changing global market and also provided three alternative combinations of innovation capabilities for the success of apparel industries.

For formulating best innovation capability recipes that can lead apparel firms towards higher innovation performance, the study used structured questioner administered through the help of IPDC (industry park development office). In general, this paper is organized into literature review, the methodological approach, the result, discussion and finally the conclusion parts.

2 Literature review

2.1 What is Innovation?

What the big names tell us about innovation in the playfield is that, it is difficult to get a common definition for it. Lorenz (2010) asserted this as; “The diverse understanding of the term ‘innovation’ may be due to different research goals, but may also be caused by the nature of the interdisciplinary research field of innovation management.” The multi-view nature of innovation among scholars emanated from every author, as s/he perceives innovation differently. However, the term innovation as it has been magnified by the great economist Joseph Schumpeter (1883-1950); was originally a Latin term, which means ‘to create something new’.

This catchword is currently active and seems to continue in the future. Rajegopal (2013) pointed out the reasons for importance of innovation as; ‘uncertain and turbulence business environment, the fall of information costs as the web becomes more fully adopted, and consumers are demanding more, greater focus on cost-cutting’. Moreover, today there is a consensus among scholars that innovation is an essential driver of the growth and well-being of nations, affecting and providing benefits to consumers, businesses and the economy as a whole (Cornell University, INSEAD, 2017).

2.2 Innovation Capability

Ulrich (2002) as cited on (Lorenz, 2010) point out that innovation shall not be considered as an event, rather it depends upon the culture of an organization. Organizational culture is an important moderator for creating consistent and sustainable environment for innovation to flourish. This organizational culture becomes essential for firms for managing and creating innovation in the long term and termed as innovation capability(IC) (Smith et.al., 2008). Consequently, now a day's IC has attracted scholars from many disciplines. Lawson & Samson (2001) defined IC as; "the ability to continuously transform knowledge and ideas into new products, processes, and systems for the benefit of the firm and its stakeholders."

2.3 Innovation capability's influence on apparel industries

Innovation capability measures so far backward tracked to Zawislak's (2013) work in a way that they used four capability measures and assumed innovation as a result of any combination of these capabilities. Reichert et.al., (2016) used these four dimensions (operational, management, transaction, developmental) innovation capability to low-tech industries.

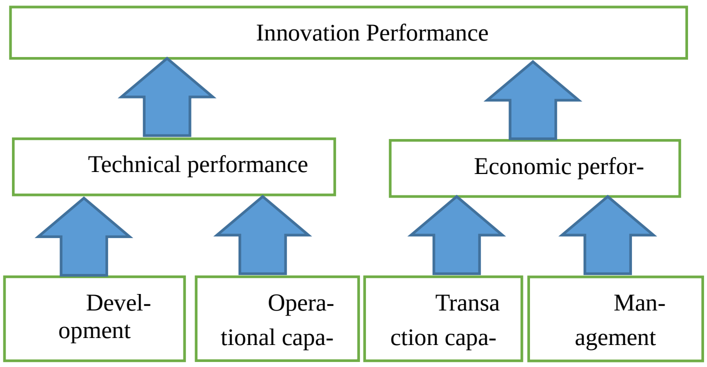

Figure 8Zawislak's innovation capability dimensions

Source Zawislak's (2013)

Operational capability (OC) of a firm can leverage the firm's skill, knowledge, and technical know-how for success in its innovation realm. This competence can align the firm's business strategy to strategic market orientation. As a result, delivery time and overall quality of service can be improved. To reduce costs with suppliers and customers through commercial strategies, improve relationships with suppliers, and streamline market knowledge, transaction capability (TC) can be considered as a critical competence of a firm. According to Tello-gamarra & Antônio (2013), it is just a set of skills, knowledge, and routines that the firm develops to operate in the market with minimum possible cost. Furthermore, it engages the firm to interact with the external environment, both to buy inputs, and to sell its finished goods and services. For low-tech manufacturing industries like the apparel industry, these innovation competencies are vital since the industry is more of a market-oriented type(Pavitt, 1984).

Conforto et al., (2016) defined improvisational capability as; "the ability to create and implement a new or an unplanned solution in the face of an unexpected problem or change." It is often seen as a spontaneous, intuitive, and creative problem-solving behavior. Kung (2019) show improvisational capability as innovation capability for tackling uncertainty and change in today's business environment and future competitiveness schemes. Sara Öhlin (2018) proved that for apparel firms' time-sensitive nature, IC is a vital for sustainability. Furthermore, today point-of-sale technologies have enabled retailers to analyze trends and act accordingly. This information enabled them to act, quickly produce, and stock goods according to the market needs with efficient cost and time. Therefore, apparel industries need to improvise as today's customers have less patience to wait. cturing/speed to market/ to apparel industry is just one of the significant competitive weapons over its competitors.

Development capability (DC) is the firm's ability to absorb and internalize new knowledge and apply it to new products (i.e., not only using technology but also generating and managing technical changes)(Reichert et.al., 2016; Zawislak et.al., 2013). On the other hand, management capability (MC) is the ability to coordinate efforts to transform technological outcomes into a coherent operational and transactional arrangement(Zawislak et.al., 2013; Zawislak, Alves, et. al., 2012). This competence has the potential to affect the competitiveness of apparel industry.

2.4 Innovation Success Recipes Configuration

Several recent studies have showed that the influence of single R&D based innovation approach cannot be sound enough for maximized innovation performance of a firm. In the same analogy, single innovation capability approach is inconsistent and no single innovation capability attains overall innovation performance of a firm. Recently there is a tendency in scientific community to investigate multiple innovation capabilities configuration for innovation performance of a firm. Thus, there may be many ways to achieve this outcome, grounded upon configuration of innovation success recipes. Woodside (2015) suggested that no single factor is likely to be sufficient or necessary when analyzing the complex phenomenon of success. Therefore, it is expected that multiple success recipes can result in higher innovation performance. This issue is hardly addressed so far. Reichert et. al., (2016) have used fsQCA and PCA analysis to explore low-tech innovation capability success recipes towards higher innovation performance of a firm. Fotiadis et. al., (2016) also used this approach to explore activities necessary for success in rural tourism. Bacon et.al., (2019) also configured conditions required for the success of knowledge transfer.

The conceptual framework developed in this work is based on the (L. A. Kung & Kung, 2019; Zawislak et. al., 2013) innovation capability articulation. The existing innovation success recipes developed by Reichert et. al., (2016) is generally for low-tech industry, but within the low-tech industries, heterogeneity problem was not considered. Moreover, the sustainability issue is not addressed in the existing work. Based on this gap this work developed a conceptual framework considering those gaps.

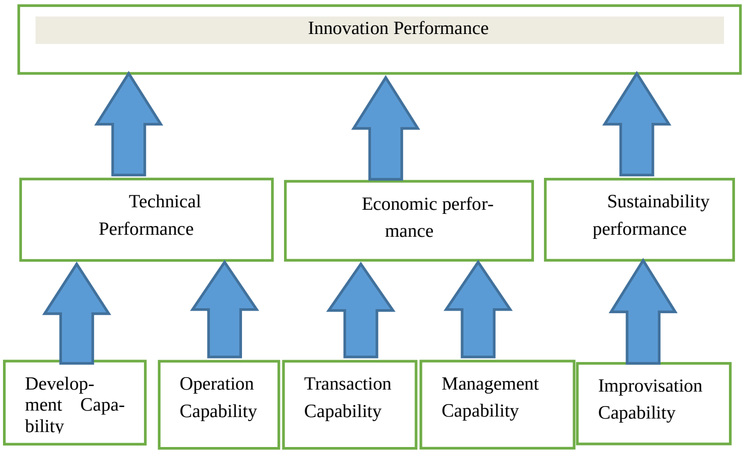

Figure 9 Study conceptual framework

Source authors conceptualization from (Kung, 2019; Zawislak et al., 2012, 2013) work

2.5 The lessons from the studies and gaps

Cao (2013) find that well organized and initiative-taking improvisational capability can speed up the process of business model innovation activity of a firm. Whereas, Wang suggested a model that describes the role of improvisational capability in generating new product development through product effectiveness and process efficiency. Both of these studies considered the improvisational capability as the best organizational competence to be competitive via high innovation performance in the dynamic and turbulence environment. The other important dimensions like operational, developmental, management, and transaction capability suggested so far need to be seen in a comprehensive way for new product development as well as business model innovation within organizations. Furthermore, Sara Öhlin (2018) was very much interested in how innovation happens, or does not happen, in every-day work. She analyzed the fashion industry in her study to exploit the significance of improvisational capability for high innovation performance in the sector. She also analyzed the enablers and barriers of innovative activities in a creative yet routinized characterized fashion industry. She suggested that the combination of the change in elements, the alignment among practices, and the way practitioners respond in innovative ways all together form improvisational capability and practice based approach to innovation in the fashion industry setting. Her proposal to fashion industry innovation performances ascertains that innovation shall be perceived both as planned and improvised approach.

Reichert et.al., (2016) innovation success recipes configuration used the four conventional innovation capability dimensions and come up with two alternative solutions for higher innovation performance for low-tech industries. Their study lacks the sustainability dimension in a way that firms shall respond to the uncertain and turbulent environment. For example, in the current global scenario covid-19 pandemic, those firms that have not built the improvisational capability can easily be perished from the market.

Therefore, this study tackled to integrate this all discrepancies of innovation capability dimensions required for higher innovation performance of a firm. No prior studies have attempt to include all this five innovation capability dimensions (management, operational, developmental, transactional, and improvisational) capabilities all together to prepare best ingredients for apparel industry innovation success.

3 Method

3.1 Data

Considering the scarcity of well-organized non-R&D innovation evidence, the study conducted survey. The authors collaborated with industry park development corporation (IPDC) office for operationalizing the survey. The information gathered for this study was obtained by a structured questioner survey administered through the help of IPDC office. IPDC office facilitated both the online survey and paper-based survey (i.e. for industry parks located in Addis Ababa). The survey included more than one informant per firm to mitigate individual perception and aiming to obtain more appropriate feedback (Simons et. al., 2001). From the 17 companies included in the survey, on average 6.412 surveys were received from each company, for an average response rate of 71.22% from each company with a minimum of one and a maximum of eight with median response of six. Furthermore, the responses were filtered out according to the criteria. As a result, incomplete or missing data, questionnaires filled with abnormal response, and not innovative firms were excluded. Totally, 109 complete responses were analyzed.

3.2 Measures

The quantitative survey approach was employed and the developed questionnaire was a structured type. The items in the questionnaire were quantified and constructed to be measured with a seven-point Likert scale (one=not very important, seven=very important). The questionnaire contained four sections covering (1) respondent and company profile, (2) innovation capability of the company, (3) non-R&D innovation practices, and (4) innovation performance of the company.

The survey questionnaire were tested by three experts each from academic institution, ETIDI research center, and industry consultants to make sure whether the respondents understood the questions or not. Accordingly, minor formatting and presentation modifications were made. Subsequently, the questionnaire was distributed to middle level and top level managers electronically through the online survey tool called Google docs. ETIDI and IPDC webpage were referred to get the address of the selected respondents. Furthermore, the respondents were allowed to invite the questionnaire to another expert in the field if they were sure that s/he was unfit to answer the questionnaire. The respondents were contacted through email first and then reminded through phone. To get respondents trust on the data gathering process, cover letter sealed and signed by the school dean and supervisor were sent with questionnaire.

3.3 Estimation strategy

3.3.1 Principal Component Analysis (PCA)

From the conceptual framework developed from the literature analysis, 28 items was originally presented to three experts before the survey conducted and finally 23 items were included in the survey. Respondents rated their concern about the importance to each innovation capability item using a seven-point scale ranging from “not very important” to “very important.” principal component factor analysis used with varimax rotation to extract factors from these items.

Innovation performance measure described by Schumpeter (2008) were applied. Net profit growth, market share growth, and revenue growth constructs taken from Schumpeter to capture economic performance of the firm. We let the respondents to reveal their level of satisfaction using seven point Likert scale ranging from one to seven. One is indicating for ‘very dissatisfied’ and seven for representing ‘very satisfied’.

3.3.2 Fuzzy-set Qualitative Comparative Analysis (FsQCA)

FsQCA first introduced by a social scientist Charles Regain (2008) and it uses qualitative and quantitative assessments to compute the degrees during which a case belongs to a certain set. This method mainly focuses on the complicated and complex relations between the result of interest and its antecedents. Furthermore, fsQCA is employable on a various sample sizes starting from very small (i.e. below fifty cases) to a very large sample size (i.e. thousands of cases) and it is also suitable for various styles of data (e.g., Likert-scale, click streams and multimodal data)(Pappas & Woodside, 2021). In this study, for the purpose of appropriate combinations of innovation capabilities, fsQCA method was employed. It uses Boolean algebra and fuzzy-set theory to identify each case with a set of specific traits, causal conditions, and outcome. Using fsQCA 3 software, the study identified innovation capability causal recipes that lead to high innovation performance.

Since the variable construct in this study is measured through multiple items, it needs to be computed to one value per construct that could be suitable input to fsQCA software. Therefore, we have calculated the mean of our desired outcome high innovation performance (High InnP), and other five conditions (IC, MC, OC, DC, and TC). Therefore, the study aspires to test the following fsQCA model;

$$\text{High InnP} = (\text{IC, MC, OC, TC, DC}) \quad \text{Eq (1)}$$

Data calibration was done through direct method by choosing threshold values 0.95, 0.50, and 0.05 as break points to transform data from Likert scale to fuzzy set. The fsQCA manual (Ragin, 2008) were followed to perform fuzzy-set calibration and three breakpoint criteria’s (0.05 for the full non-membership threshold; 0.50 for the crossover point; and 0.95 for the full membership threshold were used(Ragin, 2008). Accordingly, the variables were calibrated from zero to one.

In this study, the truth table has 32 rows, which is from all logically possible configuration of the five conditions, where 2k=5 (Ragin, 2008). After feeding the converted data to the software the outcome sorted by frequency and consistency. In order to reduce the quantity of rows in QCA analysis of sufficiency, a range of a consistency level and a frequency threshold is needed. Ragin (2008) suggested a consistency level of higher than 0.75 as a rough benchmark. This study applied a consistency cut-off from 0.79.

FsQCA software calculated number of observation per each combination as frequencies. Following this truth table sorted by frequency and consistency. Next to this, all combinations with smaller frequency were removed for further analysis. After removing configurations with low frequency, the truth table have been sorted by raw consistency. FsQCA software also provides all three solutions every time. The combined solutions of both parsimonious and intermediate revealed in detail and aggregated view of the findings. To simplify and improve presentation of the findings, the outcome of fsQCA transformed into a table that is easier to read.

3.4 Research framework

This study aims at understanding the causal relationships between important aspects of apparel firms' innovation capabilities with their innovation performance. Ethiopian apparel industry recently attracted billions of dollar from FDI. The multinational apparel firms working in Ethiopia's industry park created an opportunity to capture primary data for the study. The study at initial stage focused on understanding the theoretical perspective of low-tech innovation capability. After identifying relevant information; questionnaire development, questionnaire validation, data gathering, and compiling carried out. Following this, compiled data were estimated using PCA and fsQCA. Finally, the result validated by sub-group analysis. The methodological framework followed is presented in Figure 3 below.

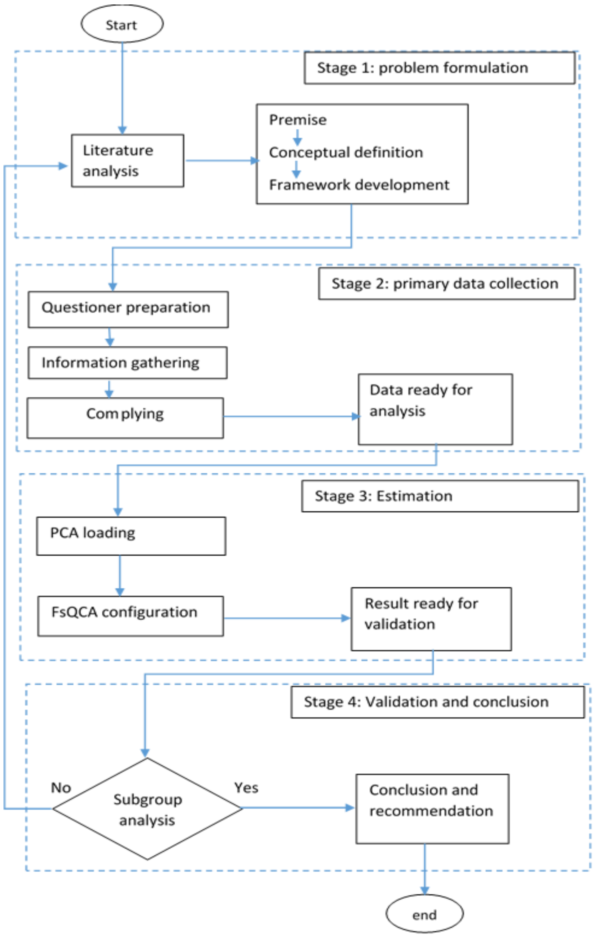

Figure 10 research framework

4 Results

4.1 Summary of Survey data

The list of low-tech innovation capabilities practiced by apparel manufacturing multinational firms operating in Ethiopia is shown on Table 1 below. Totally 109 complete responses were used for analysis. As pointed out by the mean scores, 'to respond in the moment to the unexpected problems' together with 'coming up with new ideas' and 'to successfully reconfigure resources to react to customers demand' are most practiced low-tech innovation capabilities. Whereas, 'to impose its price on the market' and 'to use formal criteria to select its suppliers' are the lesser-practiced innovation capabilities.

Table 5 Summary of Survey Data

Variable	Obs	Mean	Std.Dev.
Designs its Own products	109	5.56	1.6
Develop creative solutions for unperceived situations	109	5.36	1.08
Develop products in partnership with STI	109	5.21	1.6
Establishes a productive routine that does not generate rework	109	5.34	1.43
Formalizes procedures of planning and production control	109	5.30	1.44
Imposes its negotiating terms on its customers	109	5.39	1.25
Imposes its price on the market	109	4.84	1.23
Maintains its personals well trained for company functions	109	5.68	1.16
Maintains statistical control of its process	109	5.42	1.00
Maintains the material stock level appropriate to the process	109	5.63	0.87
Makes CSR its core agenda	109	5.44	1.30
Measures its customers satisfaction	109	5.25	0.93
Monitors the latest technological trends in the sector	109	5.91	0.92
Resolve problems using available resources	109	5.65	1.15
Respond in the moment to the unexpected problems and come up with new ideas	109	6.25	1.01
Skillful in reusing existing resources to serve customers	109	5.39	1.31
Standardizes and documents its different working procedures	109	5.37	1.47
Successfully reconfigure resources to react to customers demand	109	5.94	0.97
Traces the market to monitor	109	5.15	1.17
Updates its management tools and techniques	109	5.27	1.44
Uses current financial management practices	109	5.57	1.25
Uses formal criteria to select its suppliers	109	4.81	1.90
Uses formal project management methods	109	5.64	0.92

The survey result also reveals there are a wide range of variation among the companies in innovation capabilities like 'design its own products', 'use formal criteria to select its own suppliers', and 'develop products in partnership with STI'.

4.2 PCA loadings

From the PCA loading, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy is 0.899 and the Bartlett's Test of Sphericity is significant (pb 0.000) and the results confirm five capabilities. The items loading: improvisational capability (five items with Cronbach's α = 0.922), management capability (five items with Cronbach's α = 0.898), operational capability (four items with Cronbach's α = 0.929), developmental capability (four items with Cronbach's α = 0.796) and transaction capability (five items with Cronbach's α = 0.895). Table 1 below shows list of innovation capability item loadings.

Table 6 Principal component analysis loading

	Component				
Rotated Component Matrix	MC	IC	TC	OC	DC
Updates its management tools and techniques	0.923				
Standardizes and documents its different working procedures	0.896				
Maintains its personnel's well trained for company functions	0.802				
Uses current financial management practices	0.623				
Makes CSR its core agenda	0.563				
Resolve problems using available resources		0.899			
Respond in the moment to the unexpected problems and come up with new ideas		0.865			
Successfully reconfigure resources to react to customers demand		0.713			
Skillful in reusing existing resources to serve customers		0.694			
Develop creative solutions for unperceived situations		0.626			
Imposes its negotiating terms on its customers			0.956		

Imposes its price on the market			0.919		
Traces the market to monitor			0.864		
Measures its customers satisfaction			0.860		
Uses formal criteria to select its suppliers			0.620		
Maintains the material stock level appropriate to the process				0.915	
Maintains statistical control of its process				0.885	
Establishes a productive routine that does not generate rework				0.680	
Formalizes procedures of planning and production control				0.660	
Designs its Own products					0.921
Develop products in partnership with STI					0.898
Monitors the latest technological trends in the sector					0.662
Uses formal project management methods					0.615
Cronbach alpha	0.898	0.922	0.895	0.929	0.796
Eigenvalues	4.83	4.73	4.5	3.77	2.54
Percentage of variance explained	20.13	19.69	18.74	15.72	10.56
Mean	5.54	5.41	5.09	5.58	5.72
SD	0.595	0.587	1.06	0.576	0.282

4.3 FsQCA results

From the fsQCA analysis, three configurations of innovation capability recipes that lead to high innovative performance in apparel manufacturing firms were drawn: IC*MC*TC (solution 1), IC*DC*TC (solution 2), and IC*OC*TC (solution 3). The consistency for the three solution and for the overall solution exceed 0.75(Ragin et.al., 2008). Therefore, these recipes are sufficient to cause high innovative performance. The combined recipes for the first solution account for 78.2% of membership in the high innovation performance outcome. The second and third solutions are 75.6% and 75.1% respectively.

Table 7 Recipes for achieving high innovation performance in apparel industry

	Solution configuration	Consistency	Raw coverage	combined
	IC*MC*TC	0.887522	0.650773	0.782130
	IC*DC*TC	0.886314	0.607818	0.755876
	IC*OC*TC	0.874652	0.606959	0.751313

One major challenge of fsQCA is the robustness and validity of the results. So far scholars suggested that the sensitivity of fsQCA is sever if slight parametric change occurs, the outcome from fsQCA can easily be deteriorated (Krogslund et.al., 2015; Lucas & Szatrowski, 2014; Skaaning, 2011). There are two robustness tests which are commonly applied(Meier, 2017). The first one is by sub-sampling which aims to address concerns about fsQCA application in large sample size setting and to increase confidence of results(Meier, 2017). The second robustness test applied by Emmenegger & Schraff (2014) aims at demonstrating that the results are insensitive to small changes in data and rather the data is analyzed for about 1,000 runs while randomly deleting 10% of the data in each run(Meier, 2017).

This study employed the first approach for the robustness test. Therefore, the robustness test is conducted by following the approach of Reichert et.al., (2016). First, the study randomly split the total sample into two equal sub-samples and modeled each sub-sample by using the results of sub-sample 1 to predict the scores in sub-sample 2 and performing the reverse procedure for cross-validation. Table 3 and Table 4 show the predictive validity for each sub-sample.

Table 8 Using sub-sample 1 to predict scores in sub-sample 2

	Solution configuration	Consistency	Raw coverage	combined
	IC*MC*TC	0.877522	0.640773	0.772130
	IC*DC*TC	0.856314	0.597818	0.752876
	IC*OC*TC	0.844652	0.596959	0.750313

Table 9 Using sub-sample 2 to predict sub-sample 1

	Solution configuration	Consistency	Raw coverage	combined
	IC*MC*TC	0.867522	0.630773	0.762130
	IC*DC*TC	0.854445	0.597818	0.753876
	IC*OC*TC	0.854652	0.586959	0.750013

5 Discussion

For low-tech industries, innovation is born out of a set of innovation capabilities of a firm. In addition to the four conventional sets of low-tech innovation capabilities, we have added one extra dimension and configured to bring the right set of success recipes that can lead apparel industries to higher innovation performance. Configuring success recipes is a recent phenomenon for exploiting higher performance in various sectors(Bacon et.al., 2019; Fotiadis et.al., 2016; Nguyen, 2017; Oliveira et.al., 2019; Reichert et.al., 2016).

Regardless of the machinery and labor, from which cloth is made, lately, the apparel is expected to be produced with the concept of quick response. Therefore, the entire apparel supply chain needs to be more agile, which means that stakeholders need to have better visibility, speed, and flexibility. Furthermore, today's point-of-sale technologies have enabled retailers to analyze trends and act accordingly. This information enabled them to produce quickly and stock goods according to the market while attaining efficiency interms of cost and time. Therefore, the improvisational capability (IC) of a firm comes here to address this issue.

Apparel industry, due to its labor-intensive nature, needs a large workforce. Therefore, a favorable work environment and safe conditions are essential for the betterment of the workers to ensure fast, reliable, and efficient production environment. The Rena Plaza 2013 incident that caused thousands of deaths in Bangladesh initiated stakeholders to introduce several multi-stakeholder workplace safety compliance initiatives. Following this, global consumers mostly US and UK buyers have become increasingly concerned about the treatment of workers in the apparel industry. In response to increasing pressure from the international and local media, international buyers and traders have become more sensitive to the working conditions in the supplier factories and are now considering the issue with more importance. Thus, better working conditions have become one of the main competitive factors along with low cost and preferential market accesses(Selvanathan et.al., 2019). Accordingly, management capability and operational capability can enhance the competitive advantage to the firm.

The bargaining power of buyers today is powerful than manufacturers. Therefore, consumers dictate when, what, how, and where they wish to shop. That resulted a threat to the traditional apparel readymade product business model. Therefore, apparel industries in current scenario need to create a means to predict their customer's buying experiences. Connecting individual items via a digital thread, products, and sellers will be able to communicate directly with the customers, with customized communication that is based on the customer's needs and concerns. Therefore, transaction capability and developmental capability can enhance innovative performance of the firm in this regard.

Therefore, the first alternative with improvisational capability, management capability, and transactional capability (IC*MC*TC) recipes leads to better innovation performance of apparel firms. Improvisational capability enables agility of the firm and ensures apparel firms dynamic response in market. The second element management capability secures firm's innovation performance through proper human resource utilization and it can go hand in hand with improvisational capability element. The third component of this alternative solution that is transaction capability in apparel industry can lead to better innovation performance by tracing the ongoing market trend and imposing negotiating power on its customers.

The second alternative innovation capabilities recipe for higher innovation performance in apparel industry comprises improvisational capability, transaction capability, and developmental capability (IC*TC*DC). The only difference of this set of capabilities from the first one is the substitution of management capability to developmental capability. Developmental capability can lead the firm launch their own products and collaborate with other institution for firm's new product development success.

The third set of capabilities configured to higher innovation performance comprises improvisational capability, operational capability, and transactional capability (IC*OC*TC). Like the second alternative, the only difference in the third recipe is the appearance of operational capability to substitute management capability of the first recipe and developmental capability of the second recipe. Operational capability ensures firms innovation performance through higher process efficiency and reduction of rework.

Improvisational and Transaction capability are among the core conditions of success recipe in all of the three alternative solutions. Improvising in this ever-changing environment and volatile global market can be supported through information technology assisted organizational memory and cross-functional teams(Wang, n.d.), and it enhances innovation performance through process efficiency and product effectiveness. Whereas, transaction capability is a result from the learning process through which firms measure its customer satisfaction and track the market to respond accordingly(Zawislak, Alves, et.al., 2012). The difference of results from this study and Reichert et.al., (2016) is in a way that they considered low-tech industry in general and in this work apparel industry in particular was scrutinized. Furthermore, in their work they only considered only four innovation capability dimension and this study added one more improvisational dimension which is vital for apparel firms performance (Sara Öhlin, 2018).

6 Conclusion

The main target of this study is just to investigate the best innovation success recipes that can lead to higher innovation performance of apparel industry. Overall, the results provided evidence that, there are three possible alternative pathways to higher innovation performance of the sector. These innovation success recipes can be applied for better innovation performance.

Within low-tech industries apparel industry is one among them. Innovation in this context is triggered by different factors. Time sensitive nature of the industry and the technological dynamics greatly affected this sectors innovation approach. The findings revealed that for apparel industry sustainable competitiveness through high innovation performance there has to be one more innovation capability, which is improvisational capability.

The PCA result gives five capabilities (improvisational capability, management capability, operational capability, transaction capability, and developmental capability). Whereas, the fsQCA analysis configured these five low-tech innovation capabilities to figure out best recipes that enable apparel firm's innovation performance in ensuring their sustainable competitiveness. Three alternative solutions configured that can bring high innovation performance in apparel industry. Improvisational and Transactional capabilities found in all three alternative solutions.

A couple of limitations are believed to exist in this study: First, the self-reported nature of the study data may lead to an over-optimistic assessment of the levels of innovation capabilities and innovative performance. Second, fsQCA approach is too sensitive to the specific conditions included in the configuration analysis and consequently adding or removing conditions can significantly alter solutions. Therefore, as future study it is possible to cross validate the results of fsQCA with other approach such as fuzzy in Stata. Likewise, this work can be advanced through a large set of data for more significant outcome and the approach can be applied to other low-tech sectors.

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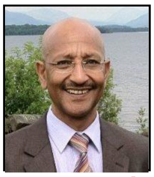

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