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Goal-based Key Performance Indicators of Science Parks' Effectiveness: A Case Study at Riyadh Techno-Valley

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Science and Technology Parks (S&TP) play an important role in creating a supportive eco- system to build innovation, developing new businesses, transferring of technologies, establishing tight collaboration with the industry and positively impacting the growth of knowledge economy. To successfully manage this eco-system and determine its significance a well-defined evaluation system is needed to continually assess the performance of S&TP. In this paper, a procedure for measuring the effectiveness of Riyadh Techno Valley (RTV) using a set of comprehensive and well known multi-criterion performance indicators has been described. The performance indicators are assessed in relation to the goals of RTV by estimating its optimal achievement values and compared to actual performance to determine the gaps and recommend appropriate improvement. Due to uncertainty in human experts' judgment psychometric fuzzy scale have established to measure the actual against the optimal overall performance.

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Keywords: Science park; multi-criterion decision analysis; multiple goal-based analysis; fuzzy sets assessment; effectiveness assessment; knowledge-based economy (KBE).

1. INTRODUCTION

The science parks have a critical role in development of technology and are able to make economic growth of the countries [1]. Taking this fact seriously, the United States was a pioneer in a knowledge-based economy in the 1950s through establishing the Silicon Valley in California, and the Research Triangle Park (RTP) located in North Carolina. The first person to have used the expression of "knowledge-based economy" was Peter F. Drucker in his book *The Effective Executive* [2]. In this book, Drucker distinguished between hand labor and knowledge labor. However, this categorization of hand labor and knowledge labor is somewhat unfair since all kinds of work involve the intellect. A knowledge-based economy is a knowledge-driven one in which the production of and investment in knowledge plays a major role in generating wealth. Acquiring knowledge doesn't necessarily means achieving progress in the knowledge based economy, unless it links to initiatives that can be executed in a proper way according to well-known criteria, in addition to healthy management process that allows monitoring the execution progress so it transfers this knowledge into valuable products.

In order to understand the value of the Knowledge Based Economy (KBE) and its contribution to the national's economy, the system knowledge needs to be looked at first to determine the main components of KBE. Successfully realized KBE requires effective knowledge management (KM). Managing system knowledge is related to the mechanism of creating, storing, sharing, and disseminating knowledge. By the mid-1990s, KM initiatives were flourishing because of the wide spread of the Internet.

KM is related directly to the effectiveness with which managing the knowledge enables members of the organization to deal with today's situations and effectively envision and create their future [3]. A sound KM depends on its effective distribution and not only on its efficient production. Therefore, effective KM requires successful collaborative platform strategies that provide value for users by improving knowledge sharing. This can be done through secure wireless network that has the advantages of flexibility, mobility, easy administration, reducing the information-related risk, and support of security [4].

A knowledge society is an indication of the ability of society to produce and use of knowledge as well as sharing of knowledge using the proper technology [5]. Networks encourage sharing of knowledge and play an important role for bringing innovation-specific resources and expertise for entrepreneurial teams to create new opportunities [6], and [7]. Stakeholders such as government agencies, universities, science parks, suppliers and competitors have a great influence on innovation [8]. In addition, partnership between industry and universities has been considered in many countries as part of national policies to strengthen innovation. Most innovative firms, around 90%, had formal links with universities according to study done by Wilkinson, Lawson, Keeble, Lawton-Smith, & Moore [9]. Additionally, a significant relationship was found between the introduction of new products and university networking [10]. Hence, collaboration among universities and industries as well as government agencies, science parks and investors is highly recommended for successful innovative products. In order to benefit from the innovations through creating or enhancing the characteristics of associated products at science parks, investors need to be encouraged for spending enough funds for the development. This can be done by providing a fair partnership model that intends to identify the role, right, and responsibility of each party as described in [11], in addition to providing a good incentive program to attract the Venture Capital (VC) fund to support the project development.

As a premise for assessing the organizational KM capability and performance, there are methods used worldwide to determine the organization's readiness not only to implement KM, but also its readiness to be truly a knowledge-based, knowledge driven organization. However, this method focuses on the descriptive question/answer approach to determine the gap, which can't be quantified to measure the organization performance. There is other method used by the World Bank to assess the knowledge which is known as "Knowledge Assessment Methodology (KAM)", by Worldbank [12]. This method includes 109 parameters which can be used to assess the core of knowledge. There is no correlation among the different parameters used in this assessment so we can measure properly the overall performance indicator for a particular nation. These parameters used for measuring the effectiveness are grouped in 8 elements. These elements are economic performance, system of economy, government, innovation system, education system, workers, equal employment opportunities, and ICT. Evaluation of these parameters is subjective and is based sometime on absolute values, or relative values. In order to complete the assessment of a particular country, the KAM method requires covering the 109 parameters, where many variables have to be considered. The World Bank had also reduced the grouping to six which are Knowledge Economy Index, Knowledge Index, Economic Incentive, Innovation, Human capital, and ICT. An analytical method that is based on how the probability of the knowledge factors can occur in a certain environment has been suggested to quantify the performance of certain organization [13]. This new method would allow managers to evaluate the performance of knowledge based economy of different nations or organizations and assist them in identifying problems and guide them on how to plan for improvement.

In this paper, the key performance indicators (KPI) have been identified to align with the 4th generation science parks where they are grouped according to four functions that are R&D, Business, Management, and Infrastructure. These KPIs are associated with the main components or activities of these groups. These KPIs are linked to the goals of a Science Park, where the optimum values are defined. Then an estimation of the value of certain Science Park would be estimated according to survey form given to few experts and then the average weight of the PKIs is determined. This will allow managers to compare the result of the survey to the optimum value in order to determine the gap and therefore the recommendation for improvement as will be described in the following sections.

2. ESTABLISHING ECO-SYSTEM AT RTV

RTV Research and Business Development department is aiming to develop an eco-system for the knowledge based economy at King Saud University at all phases that deals with the creation, transfer, dissemination and utilization of knowledge, and then monitoring the knowledge management. Section 2.1 describes the main goals of RTV in order to establish a 4th generation science park. The realization of this eco-system would allow the transfer and habitat of technology to RTV and the Kingdom of Saudi Arabia towards creating useful products for achieving a strong knowledge based economy as shown in Fig. 1. This eco-system would have a great effect on innovation once a proper collaboration between KSU University research departments and private as well as public local and international R&D sectors, has been established and managed by a RTV. Section 2.2 describes how to optimally manage the phases of knowledge creation dissemination and utilization, by having effective collaboration and partnership programs between KSU researchers, national and international companies and universities, as well as government and fund institutions. In addition, innovation/knowledge economy eco-system would be established through building a smart city for attracting R&D companies to invest at RTV. Furthermore, dissemination of knowledge through events would allow sharing of knowledge and educating researchers and society. The eco-system that has been established at RTV involves the integration of all R&D units at the university along with collaboration and partnership with private and public sector in order to support the innovation toward creating useful products. Furthermore, an effective KBE requires a proper monitoring and auditing process to measure the performance of organizations as described in section 3, which is the main focus and contribution of this article. Following the monitoring of science park performance, a gap analysis would identify the difficulties and obstacles in reaching its goals and then suggesting improvement for fixing and illuminating these obstacles as will be described in section 4.

2.1 Goals of RTV (to be a 4th Generation Science Park)

The following main goals of RTV have been identified as follows http://www.rtv.com.sa [14]:

1. Transfer and Habitat of technology for sustainable development.
2. Strengthening the collaboration with national and international universities and research centers.
3. Providing excellent environment to attract R&D companies.
4. Providing opportunity to attract creative and innovative person to work at RTV.

2.2 Creation, Dissemination and Utilization of Knowledge at RTV

In the following subsections, knowledge creation will be covered as well as sharing and utilization of knowledge.

2.2.1 Knowledge creation

The education and R&D system play an important role in realizing the KBE. In order to maximize the knowledge creation, the academic system should have a high standard level that is related to the core based education and strong publication. In addition, a good education system would contribute to the creation of new ideas that leads to innovation. The transfer of technology from the academic systems and early stage of innovation can be facilitated through the help and support of incubators. The role of incubators would also support marketing of the successful innovations that can be evolved into products with the help of industries, venture capitalists, government's seed funds and through startup companies or licensing. All these efforts would have a better chance for success through government support that has favoring procedures and regulations. This integrated system is depicted in Fig. 2.

A good innovation environment and suitable culture together with business oriented incubators that support of entrepreneurship would assist in technology transfer. Science parks on the other hand with complete infrastructure, good incentives, and a proper procedure for creating partnership with local and international companies, and proper management would play important role in creating a strong KBE. Moreover, diversification of sources of funding the National Innovation System, diversifying the sources of financial support, as well as improving the regulations and legislations would increase the chance of successful knowledge businesses creation and strong KBE.

2.2.2 Sharing and utilization of knowledge

Sharing of knowledge and learning from other nations' best practices would avoid making common mistakes. Based on other ST's best practices and in order to provide the best environment for the transfer and habitat of technologies towards achieving an eco-system that is relevant for the creation and establishment of new technologies at Riyadh Techno Valley and the Kingdom of Saudi Arabia (KSA), the following initiatives associated with different collaboration programs are being implemented:

- Strengthen the relationship with leading companies to establish R&D centers at RTV and develop joint research projects with KSU researchers.
- Attract leading companies to have partnership and investment with RTV.
- Collaborate with established service and infrastructure companies at RTV to provide the best solution, support the knowledge transfer, and support the R&D projects in collaboration with KSU researchers.
- Collaborate with KSA organizations which support the R&D in the domain of ICT, Energy and other important applications to support projects sponsored by RTV.
- Collaborate with KSA universities to attract R&D projects to transfer of technology to RTV.
- Disseminating and sharing of knowledge as well as building a good network through hosting variety of workshop and conference events in relevant domains to RTV.
- Establishing smart innovation centers to provide smart solutions to the kingdom.
- Sharing of knowledge and experience with the community and developing solution for interactive environment.

3. LITERATURE REVIEW ON SCIENCE PARKS' EFFECTIVENESS EVALUATION

The survey of literature on the assessment of science parks' performance is presented in this section. In spite of being few numbers of science parks in the world, mainly and obviously distributed in the industrially developed nations, it has been indicated that there is a significant issue to the justification of fund allocated to the science parks. The issue is also significant toward guiding in the realization of the science parks intended effectiveness and continuous improvement. Some few attempts have been recorded below.

Guy, Ken [15] presented a comprehensive report for the science parks evaluation guidelines for evaluators and promoters participating in the science park evaluation scheme. The report suggests approaches and checklists of potential use to an evaluation rather than rules and rigid procedures for carrying them out. A purely subjective evaluation of Innopoli and the Otaniemi Science Park Cluster in Finland, only indicating the methodology and a set of the criteria has been presented by Koh, F., Koh, W. & Tschang [16]. They proposed an analytical framework to examine the gestation, evolution and sustainability of science parks and related to broader regional phenomena such as technology districts. The framework implicitly involved several useful science parks success evaluation criteria that could be generally considered to assess science parks' performance. The main growth mechanisms they identified were government-led infrastructure provision, agglomeration effects and continual self-renewal through the creation of new businesses. Koh's study was fully subjective lacking objectively numerical assessment and didn't present justified results. Chena & Huang [17] pointed out that little has been done in discussing the selection strategy of high-tech industries to locate in such a park. They adopted the widely utilized Analytical Hierarchy Process (AHP) [18] and [19] method to evaluate the high-tech industries to be selected in order to locate in the science park, according to multiple criteria. Their analysis resulted in seven evaluation criteria with one, the ''market potential'' having the highest weight, followed by ''technology level'' and ''government policy''.

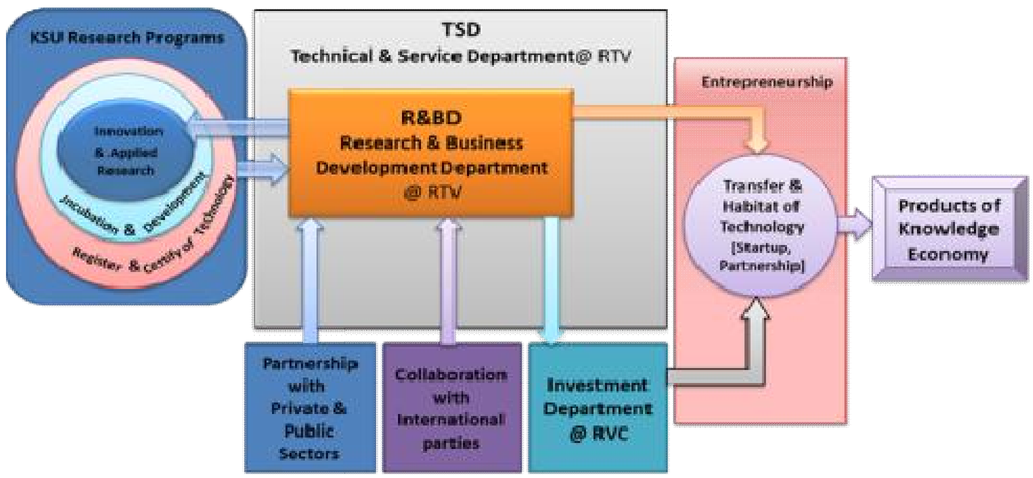

Fig. 1. RTV eco-system towards strong knowledge based economy

Fig. 2. Key factors for the creation of Knowledge for good education system

Chan & Lau [20] introduced an assessment framework of technology incubators in the science park. Based on the past studies, nine sets of criteria were identified and incorporated in the assessment framework. Using business development data of six technology start-ups in the Hong Kong Science Park, they applied the framework to examine the effectiveness of incubators from the perspective of venture creation and development process. In fact, the proposed evaluation framework was mainly subjective, where the tenant firms ranked the incubators using linguistic values like: “Low”, Medium, etc. the framework does not considered the differences in relevance or importance of evaluation criteria with respect to each different tenant. Moreover, the proposed procedure, doesn't quantify neither the criteria importance nor their achievement levels. Closely relevant to this research article is the work done by Bigliardia, Dormiob, Nosellac, & Petronic [21]. Their presented work was aimed at providing a sound and theory-grounded methodological framework to science parks performance measurement, in form of a subjective conceptual model and some practical suggestions useful for the design and the implementation of a Science Park’s (SPs) performance evaluation. Bigliardia’s major results were that the evaluation criteria should be aligned with science park actual mission, major stakeholders commitment, economic regional conditions, legal forms, nature of the scientific competence base available within research centers and SP’s life-cycle stages. However their proposed assessment methodology can be viewed as a conceptually subjective assessment model, which lacks objectively numerical assessment. Another MCDM science parks application is the Chen, Wu, & Lin [22] work which addressed the selection of high-tech industrial firms to join the science park by considering the selection of firms with better efficiency and/or growth potential in specific high-tech industries to get into the science parks with limited space availability. They applied the Data Envelopment Analysis (DEA), a multiple inputs–multiple outputs evaluation method, to analyze the comparative performances of the six high-tech industries currently developed at Taiwan’s Hsinchu Science Park.

Monck & Peters [23] discussed the benefits and problems associated with the evaluation of science and technology parks as member of the IASP (International Association of Science Parks) to propose a structured approach to impact measurement and assessment. They introduced an assessment method that contains details and an overall evaluation of main inputs and outputs to the science parks, and the activities. It connects the impacts of the science park to the analysis of the challenges and problems it confronts. The model provides detailed information about evaluating the final impact of the science park. However, it has a short-coming by focusing on the inputs and outputs, but ignoring the impacts of many functions and activities of the science park including factors and their relative importance with respect to the success of the science park. They applied such theoretical impact evaluation framework to a specific case Tamar Science Park, at UK.

Implicitly related to the science park evaluation and multi-criterion issue is the work done by Lin & Tzeng [24] who differentiated among the decisive factors effecting enterprises in choosing the right places for production, R&D and marketing. They also introduced a proposed development strategies and operation models for the authorities of science (technology) park to advance the parks’ value. They compared various industrial clusters using the DEMATEL (Decision Making Trial and Evaluation Laboratory) technique, where DEMATEL technique is used to determine the relationship between the evaluation criteria and to establish industrial structures. Four aspects were considered: human resources, technology resources, investing environments and market development. These aspects encompass 28 evaluation criteria to determine the establishment attributes of clusters. Two well-known industrial cluster parks, the Neihu technology park and the Hsinchu science park as example where they are both in Northern Taiwan, were considered as case studies for the project. Another example related to the evaluation of the science park effectiveness is the work performed by Ratinho & Henriques [25] who analyzed the population of the Portuguese SPs and business incubators (BIs) in promoting economic growth using case studies. Furthermore, they searched for the success factors of Portuguese SPs and BIs. Their study suggested a modest contribution of SPs and BIs to economic growth in Portugal. Moreover, our findings confirm university links and suitability of management to be critical to an SP or BI success in this converging economy.

Justyna [26] gave a general overview of the literature associated with the evaluation of science and technology parks, and summarized outcomes of the workshop on science parks' success held in Manchester in 2010. She proposed a matrix of key performance indicators or so called science parks' performance measurement system. The matrix of key performance indicators has been divided into four main categories: commercial, stakeholder perspective, brand and reputation and internal business processes. Under each category, several relevant quantities indicators were proposed. However, in spite the proposed matrix was quantitative, still, Justyna had not treated how to adjust the relevant importance of each indicator, and still does not gave a conclusion for how to aggregate the values of such indicators to make the finally overall evaluation comment. Sun [27] analyzed the efficiency and productivity growth of six industries in Taiwan Hsin Chu Industrial Science Park for the period 2000–2006. They utilized the Data envelopment Analysis method and Malmquist Productivity index to analyze the efficiency and productivity of the six industries. From the results, they stated that industrialists should not only enhance their managerial skills but also increase and improve innovative performance. Nahavandi, Eslami, Nosratabadi, Abbasian, & Pourdarab [1] presented a Fuzzy Expert System (FES) as Intelligent Systems to evaluate the science and technology parks. They stated that one of the problems for evaluating Science and Technology parks is to have the high number of criteria and science parks which AHP method and some other Multi-criterion decision making (MCDM) methods have evaluated parks are not suitable practically. They developed a set of decision rules to rate the score of the science parts under different settings and values of a group of influencing criteria. Wenhong et al. [28] considered the problem of evaluating the regional risk and safety conditions of industrial parks. They applied Kappa statistical analysis to evaluate the consistency analysis of the industrial park system setting of regional risk estimation, and the expert's assignment of safety conditions situation. They concluded that Kappa statistic and weighted Kappa statistic not only can be used to inspect the consistency of ordered and unordered variable data, but also can give a magnitude which reflects the consistency. Bai et al. [29] evaluated the performance of national High-Tech Zones (HTZs) in China after the financial crisis. They pointed out that, unlike previous case studies or comparative analyses, they employed the Dynamic Network Slack-based (DNSB) Measurement to open the “black box” and examine the HTZs as a connected network. Their evaluation indicated that the, first, efficiencies of both production sectors and R&D sectors are low in most Hi-tech zones, partly because the links between them are weak and the funds are inappropriate; second, the total factor productivity of the production sectors mainly depends on technical efficiency improvement, while R&D sectors hinge on technology progress. On the other hand, Albahari et al. [30] addressed the Science and Technology Parks' (STPs) heterogeneity issue. They pointed out that this issue has been mainly disregarded in past studies. They aimed to analyze the influence of different STP's characteristics on tenants' performance. They collected data on 849 firms and 25 STPs, respectively from the 2009 Community Innovation Survey for Spain. The results of the analysis of the conducted survey indicated that STPs show good innovative performance, the dimension of STPs and their management size positively affect the innovative performance of tenants, and tenants benefit more by being in STPs as they support local development policy instrument. However, STPs performance could be improved when there is no discrimination in funding projects, and increasing STP’s size would benefit tenants more as there will be more options to choose appropriate location for them. Furthermore, Jeroen Ringlever [31] assessed seven Mexican technology parks on fulfilling the requirements and definition of technology parks. He based his study on the assumption that in Mexico there was a lack of experiences about the implementation of international standards and best practices of Technology Parks. In order to provide information about the international standards and the regional impacts of technological parks in the Mexico, he conducted seven research questions, and empirical data about seven technology parks were collected. The findings of the study indicated that some of the seven parks fulfill the international definition of the technology parks, while some fewer number do not fulfill the definition, as they do not transfer knowledge. His conclusion was that most of the technology parks are not sustainable themselves and are not screening their (potential) tenants on eco efficiency/innovation yet. He also concluded that currently the measurement method of the park performance is not oriented to check the progress towards meeting the goals of the technology parks, where the international criteria of technology parks and the impact measurement are not used. It is clear from this literature review that evaluation of STPs is lacking proper assessment in terms of assessing STP's performance in relation to its goal, where this issue has been addressed in this paper.

4. MEASURING THE EFFECTIVENESS OF SCIENCE PARK USING GOAL-BASED PERFORMANCE INDICATORS

In this paper, in order to assess the performance of the science park in realizing the aspects of knowledge based Economy, a quantitative assessment methodology has been used to evaluate the outcome which will be based on identified Key Performance Indicators (KPI) that are related to realizing the Knowledge Based Economy (KBE). To achieve a sustainable nation's knowledge based economy, a 4th generation science park is the key role player for establishing an eco-system that supports innovation and entrepreneurship. The main functionality for these science parks is grouped into four categories as shown in Fig. 3.

These categories are: infrastructure, R&D, Business, and Management. The four categories are interrelated. The component infrastructure is necessary to support the other three components/activities for establishing attractive environment. Also, a proper management is needed for creating a robust R&D strategy and successful business environment. The outcome of R&D affects and derives the opportunity for creating successful business. The components associated with each category/function can comprise the good relevant sub-indicators for measuring the effectiveness of science parks as described in Table 1. The fourth column of Table 1 presents examples of component sub-indicators that are associated with the four categories/functions existed at RTV.

The first group of key performance indicators (KPI) which is associated with R&D consists of the availability and technological level of high education institutes, the existence of public R&D at science parks, the existence of private R&D at science parks, the collaboration activities with other national and international R&D, and the existence of technology commercialization. These KPIs can be used to check the capability of having the required useful knowledge, where KPI=100% means a nation would have all the required knowledge factors to build its knowledge economy. The second KPI group is the ability to invest through effectively implementing the function of Business. This group which is associated with Business includes the following indicators; ability to support entrepreneurship, availability and support of Incubators, funding innovation through Venture Capital program, and the availability and effectiveness of the business networking program. The third KPI group which is associated with management provides a good indication on how to manage innovation and how to maintain the success for managing the science park resources. This includes the following indicators; support of training programs, availability of financial aid, mechanism of marketing, availability of leased land and office for rent, globalization approach, existence of internal policy and procedure as well as national policy, and the coordination of events. The fourth and important key performance indicators group which is associated with infrastructure which plays a very critical role for providing the relevant environment for science parks in order to support a healthy execution and effective eco-system of the other functions listed in Table 1. This fourth group includes the following indicators; the allocation and land use, the R&D facilities, the business facilities, the management facilities, the availability of housing for tenant's employees, and the type of ICT infrastructure. The components or sub-indicators associated with each of the main four functions listed in Table 1 are abbreviated as shown in column 2 of this table. The fourth column of Table 1 presents examples of what programs or projects associated with different components are implemented at RTV.

In order to analyze the performance of science park in relation to the functionalities and their associated component that should be existed at every science park, first the correlation and dependencies among these functions and associated components should be identified and then a proper method for measuring the KPIs should be devised as would be explained in later in this section. Fig. 4 illustrates the four major functions of 4th generation Science Park, their components or sub-indicators and the correlation and dependencies among themselves. As shown in this figure the Infrastructure function and its components form the core part of Science Park, where the performance of the other functions of Management, Business, and R&D depend very well on the infrastructure. Moreover, there is a common component between Management and R&D which is the High Education Institute (HEI) and Human resources that are associated with training. There is also a common component between Management and Business which is

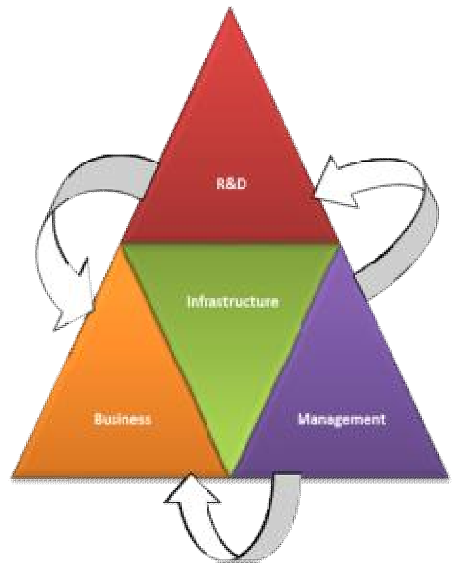

Fig. 3. Functions of 4th generation science park

Table 1. The major functions, indicators and sub-indicators of the science park assessment

Functions	Component: sub-Indicator		Eg. At Science Park
1 R&D	**A: HEI**	HEI	{High Education Institute, Like ICT, Medical, Eng, Sciences}
	B: P-R&D	Public R&D	{Nano center, Advance Technology Center, Diabetic Center}
	C: Pr-R&D	Private R&D	{SABIC, ARAMCO, CISCO, MS}
	D: C-R&D	Collaborative R&D	{Universities, National and International Orgs.}
	E:TC	Technology Commercialization	{Technology Transfer Office, VC}
2 Business	**F: Entr**	Entrepreneurship	{ Entrepreneurship college and programs}
	G: Inc	Incubation	{Incubators: ICT, Engineering, Bio}
	H: VC	Venture Capital	{VC, Innovation center, Incubators}
	I: Net	Networking	{National, International Collaboration units}
3 Management	**J: TP**	Training Program	{Training centers}
	K: FA	Financial Aid	{National Plan, Tenants}
	L: MK	Marketing	{Outreach Initiatives}
	M: PfP	Property for Rent	{Leased lands, offices for rent}
	N: GZ	Globalization	{Collaboration/partnership with KSA science parks and other international sciences parks}
	O: P&P	Policy & Procedure	{Strategic goals, templates, Guide}
	P: C&E	Coordination & Events	{Workshops, conferences, forum}
4 Infrastructure	**Q: LU**	Land Use	{ICT, BIO, Chemical}
	R: F-R&D	R&D Facilities	{Network, centers}
	S: BF	Business Facilities	{Hotel, Motel, Business park}
	T: MF	Management Facilities	{Waste, Traffic, Electrical}
	V: HS	Housing & Settlement	{Researchers' Accommodations}
	W: ICTI	ICT Infrastructure	{Basic ICT, Smart network, Datacenter}

marketing component. In addition, there is also a common component associated with technology commercialization between the Business and R&D. Each of these group indicators is composed of components or sub-indicators which can be assessed by linking them to the relevant goals of a science park. For example, the goals of the university's science park (eg. RTV) can be linked to the sub-indicators of all groups as shown in Table 2. In order to identify the relationship between the goals of science park and the main indicators that are needed to establish a 4th generation science park, we need to assign the optimum value of each indicator in relation to the goal where the optimum value can be quantified according to its relevance to achieve the goal as shown in the estimated optimum value in Table 2. The methodology for assigning relevancy of a particular component/sub-indicator to each goal can be classified according to four levels, and similarly using four scales for quantifying the achievement level of these sub-indicators as shown below:

The following sub-indicators [A, B, …, W] of indicators [R&D, Business, Management, and Infrastructure] can have the following weights:

- 0 (not important): Not needed for achieving the goal
- 1/2 (half important): Could have it for achieving the goal
- 1 (important): Must have it for achieving the goal
- 2 (very important): Must have it for achieving the goal and is needed for other indicators

The same scale could be also used to quantify achievement level at each indicator and sub-indicator with respect to each goal, as follows:

- 0 (Very Low) achievement level
- 1/2 (Medium) achievement level
- 1 (High) high achievement level
- 2 (optimum) achievement level

In order to quantify the knowledge indicator, the management indicator, the business continuity indicator, and the infrastructure indicators for RTV programs which contributed to the Kingdom of Saudi Arabia (KSA)'s KBE, the relevancy of these sub-indicators in achieving the goals of RTV would be used to identify the weight factors of the all sub-indicators, which has been estimated by 3 experts at RTV as shown in Table 2, where the optimum weight of these indicators is assigned according to the above numerical weighting scale.

As an example, High Education Institute (HEI) would be important for goals 1, 2, 3, and half important for goal 4. Therefore, the optimum value of this R&D, HEI sub-indicator would have a weight of 1 for goals 1, 2, 3, and 0,5 for goal 4. The sub-indicator of ICTI of the Infrastructure is important for goal 1, and very important for goal 2, 3, 4. Hence, the optimum weight of this sub-indicator (ICTI) would have 1 for goal 1, and 2 for goals 2, 3, 4. The sub-indicator Public R&D (P-R&D) associated with R&D is not important for goal 4 since it has no effect on attracting creative and innovative person to join the science park at RTV. Therefore, the weight value of this sub-indicator in relation to goal 4 is 0.

For the purpose of consistency and homogeneity in further step of aggregation, all weights (Over goals, indicators and sub-indicators), must be first normalized, so that all sums of weights equal one, $\sum W = 1$. The normalization of weights is shown in Table 3. Table 3 gives the final normalized values of indicators, sub-indicators and goals. It indicates that the most important goal providing excellent environment, goal number 3; the most important indicator is the infrastructure, and finally, the most significant sub-indicator is the last one, the ICT infrastructure. Of course, these weight values are considered very valuable in guiding the priorities of the RTV management in allocating resources and attention. These normalized weight value will be used in aggregating the weighted values of current RTV achievements in the incoming section.

5. MEASURING THE EFFECTIVENESS OF RTV

In order to evaluate the performance of RTV Science Park using the list of KPI shown in Table 2, a survey forms were given to 3 experts to estimate the actual performance of the RTV under each sub-indicator's value. Then, these experts were averaged and aggregated as shown in Table 5.

Now, the final performance of the RTV should be weighted according to the following newly adjusted formula, that is a generalized form of the well-known weighted sum of criteria ratings (weights of the criteria x criterion's weights) to become weighted sum of goal ratings (see the following formula):

Total Aggregate RTV Goal-based Rating

$$\text{(TAGRATE)}= \sum_{i=1}^{g} W_i \sum_{j=1}^{n} R_{ji}/(RO_{ji})/n \quad (1)$$

Where:

- W_i: the normalized weight of the i^{th} goal, $i = 1,2, ..,g$.
- RO_{ji}: the optimum performance of the i^{th} sub-indicator, $j = 1,2, ..,n$.
- R_{ji}: the RTV actual performance the the j^{th} sub-indicator w.r.t of the i^{th} RTV's goal, $j = 1,2, ..,n$.

And the range of this value is [0, Σoptimal goal based sum]. Then, by comparison to the Σoptimal goal based sum, the performance of the RTV could be located and displayed on a 2D graph

The aggregation of result and utilization of TAGRATE equation (1) yields the following results:

The total actual RTV performance is 0.27, as shown in Table 4.

In order to give final interpretation of the RTV performance and at the same time in order to take account for the uncertainty in opinions of the experts, we construct a fuzzy scale to indicate the approximate (fuzzy) position of actual performance with respect to the optimum through one. As shown in Fig. 5.

In fact, Fuzzy set theory provides a framework for handling the uncertainties. Zadeh [32] initiated the fuzzy set theory. In non-fuzzy set every object is either a member of the set or it is not a member of the set, but in fuzzy sets every object is to some extent member of a set and to some extent it is member of another set. Thus, unlike the crisp sets membership is a continuous concept in fuzzy sets. Fuzzy is used in support of linguistic variables and there is uncertainness in the problem. Fuzzy theory is widely applicable in information gathering, modeling, analysis, optimization, control, decision making and supervision. We use some of its concept to construct a fuzzy linguistic scale to assess the performance of the RTV SP (see Fig. 5). In Fig. 5, the universe of discourse is determined based on the optimal value of the RTV overall weighted achievement which constitutes the maximum performance. The lowest performance is 0. Then this universe of the actual overall performance is divided into five triangular (standard) fuzzy sets: "Very Low", "Low", "Medium", "High", "Very high".

We first apply the equation (1) to the actual and optimum TAGRATE values.

The constructed fuzzy scale is simply made using triangle memberships for five fuzzy sets represent the grades of the performances. The universe of discourse should logically lies between the maximum optimal performance and the value zero, the lowest possible. Using the maximum operator we can allocate the fuzzy set of the obtained total actual performance of the TAGRATE equation. Now, using the computed actual performance which is 0.27 is easily attributed to "Low" fuzzy set. Then, conclusively, the performance of the RTV is not high but rather a hardly low performance. Then, after, we could monitor and compute the valley's actual performance and compare it periodically the given result in order to monitor and adjust of control

Based on the conducted study done at Riyadh Techno Valley, and the experiences of three experts working at RTV who have exposure to practices at developed and developing countries, Fig. 6 presents a comparison between the estimated average performance indicators of the three experts and the optimum one. It is very clear that the majority of PKI at RTV suffer from low weight compared to the optimum one as shown in the red color of Fig. 6. The value of sub-indicator Housing and Settlement (HS) is very close to the optimum value, which gives an indication that housing is almost completed. The sub-indicator of ICTI of RTV has a low value compared to the optimum one. This indicates that there is a big delay in completing the development of the infrastructure. This might be due to the reason of bureaucracy for obtaining the budget assigned by government for RTV infrastructure.

Fig. 7 presents a comparison of the PKI Infrastructure group indicators of RTV and the optimum one. The result illustrated in this figure indicates that the PKI of ICTI is very low at RTV around 2.5% compared to optimum value of 11%. This will affect the rest of PKIs as ICTI is the main core components that must be completed first in order to complete the development of the rest of components of the group of Infrastructure. The housing and settlement (HS) PKI of RTV is close to the optimum one. The management facilities (MF) and business facilities (BF) are also low compared to optimum one since they are dependable greatly of the ICTI indicator. The overall Infrastructure group PKIs is weak and affecting badly the other PKI group of Management, business and R&D. This is because all of these groups depend on the ICTI indicator which is very low at RTV. There are many reasons for the low value of ICTI at RTV which include lack of management plan to fund the infrastructure, obstacles caused by KSU policy of the legal department, lack of management plan to monitor the execution and follow up with senior management, and the lack for auditing and tracking the execution of the plan.

Fig. 8 presents a comparison of the PKI Management group indicators of RTV and the optimum one. The result illustrated in this figure indicates that the PKI of Coordination and Events (C&E) is low at RTV around 2% compared to optimum value of 5.5%. This indicates that there are few events associated with hosting workshops and conferences at RTV which bring less chance to meet with researchers and improve the collaboration with them. Financial issue and lack of human resources might affect this indicator. The Marketing sub-indicator (MK) at RTV has a low value of 1.2% compared to optimum value of 4.8%. This indicates that RTV put less emphasis on marketing which might be related to lack of human resources specialized in marketing. The remaining management sub-indicators of Training Program (TP), Financial Aid (FA), Property for Rent (PfP), Globalization (GZ), and Policy & Procedure (P&P) are also low compared to optimum ones. This indicates that are many issues associated with management require improvement. Since the management sub-indicators affect the other Business and R&D group sub-indicators as shown in Fig. 3, these other sub-indicators at RTV would also suffer from reaching the optimum value as would be explained in Figs. 8 and 9.

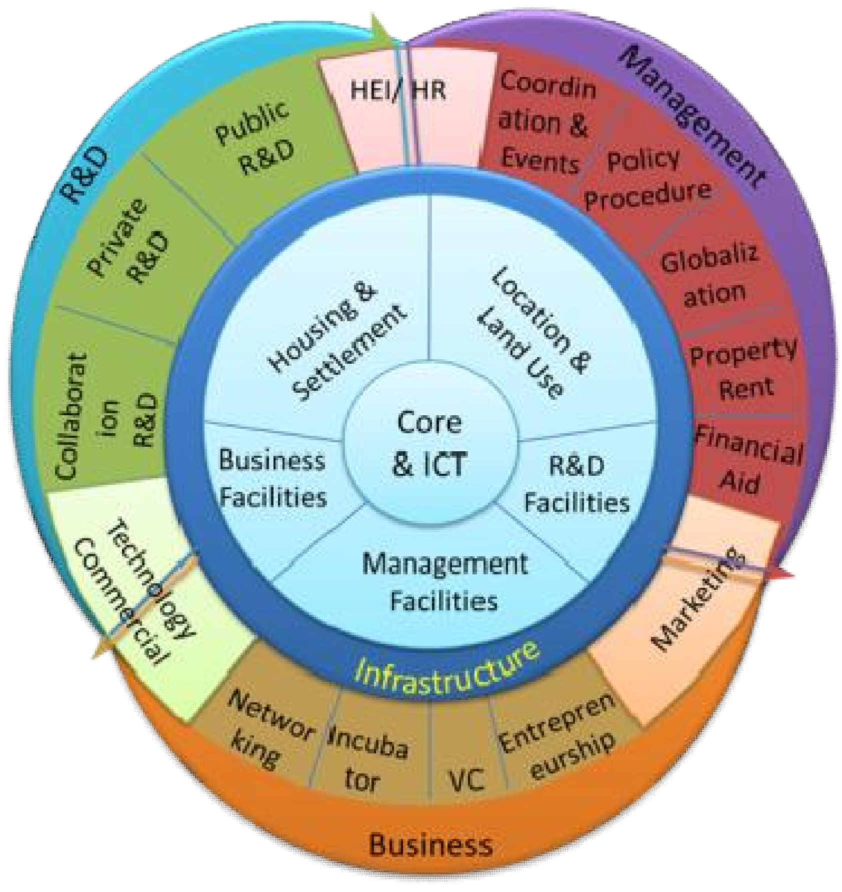

Fig. 4. Correlation between the functions of 4th generation science park

Table 2. Estimated RTV's performance indicators and sub-indicators' weights with respect to RTV's goal

RTV Goals	RTV Optimum sub-indicators value according to its goals																						Total Weight
	R&D					Business					Management						Infrastructure						
Indicators	**A: HEI**	**B: P-R&D**	**C: Pr-R&D**	**D: C-R&D**	**E: TC**	**F: Entr**	**G: Inc**	**H: VC**	**I: Net**	**J: TP**	**K: FA**	**L: Mk**	**M: PfR**	**N: GZ**	**O: P&P**	**P: C&E**	**Q: LU**	**R: F-R&D**	**S: BF**	**T: MF**	**V: HS**	**W:ICTI**	
1 : transfer & habitat of technology	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	0.5	1.0	18.0
2: Research Collaboration	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0	0.0	0.5	1.0	1.0	0.0	2.0	15.5
3: provide excellent environment	1.0	0.5	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5	0.5	1.0	1.0	0.5	0.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	19.5
4: attract innovative & creative person	0.5	0.0	0.5	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.5	0.0	0.5	0.5	1.0	0.0	0.5	0.5	0.5	0.0	2.0	12.0
Optimum Sub-indicators Weight	3.5	2.0	3.5	4.0	3.0	3.0	2.5	2.5	4.0	2.5	2.5	3.0	2.0	2.0	1.5	3.5	1.5	3.0	3.5	3.5	1.5	7.0	65.0
Optimum Sub-indicators percentage Weight to maximum 65	5.4%	3.1%	5.4%	6.2%	4.6%	4.6%	3.8%	3.8%	6.2%	3.8%	3.8%	4.6%	3.1%	3.1%	2.3%	5.4%	2.3%	4.6%	5.4%	5.4%	2.3%	10.8%	100.00%
Optimum value of sub-indicators (Normalized to ICTI)	50%	29%	50%	57%	43%	43%	36%	36%	57%	36%	36%	43%	29%	29%	21%	50%	21%	43%	50%	50%	21%	100%	

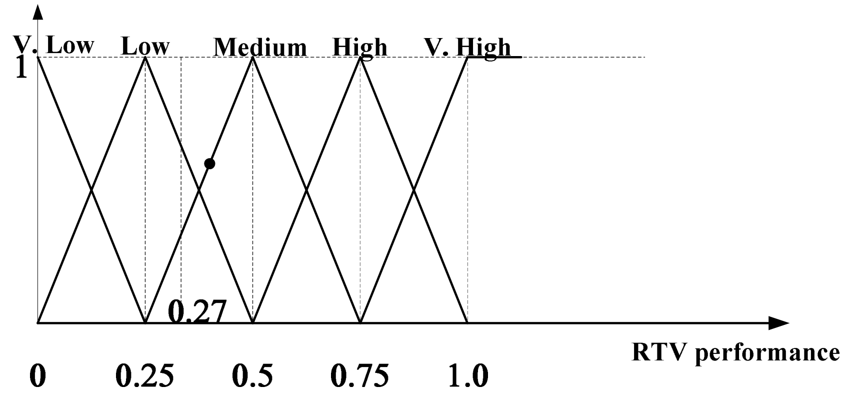

Fig. 5. The fuzzy overall scale for assessing the goal-based RTV performance

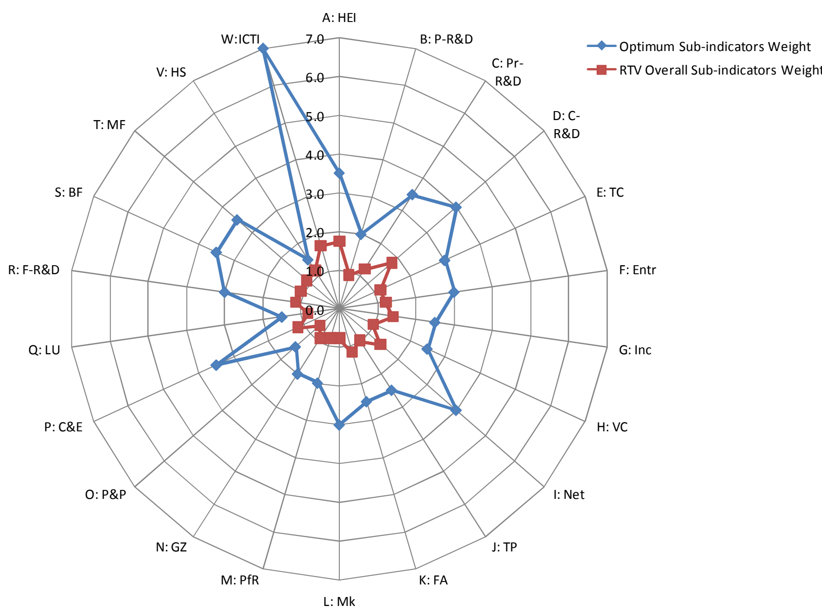

Fig. 6. Average RTV performance indicators vs optimum one

Fig. 9 presents a comparison of the PKI Business group indicators of RTV and the optimum one. The result illustrated in this figure indicates that the PKI of Networking (Net) is low at RTV around 2% compared to optimum value of 6%. This low value of Net is related to the low value ICIT sub-indicator of the incomplete infrastructure, the low value of C&E and GZ sub-indicators of the business group which affect making a proper network with professional institutions and other R&D national and international centers since there will be less opportunities to meet with these people. The value of the rest of sub-indicators of Incubation (Inc), Venture Capital (VC), and Entrepreneurship (Entr) are also lower than the optimum values. This might be due to the lower coordination among the different entities of RTV and KSU that are associated with Inc, VC and Entr, since these entities don't belong to the same management and there is no board of management controlling all these entities.

Fig. 10 presents a comparison of the PKI R&D group indicators of RTV and the optimum one. The result illustrated in this figure indicates that the PKI of Technology Commercialization (TC) is low at RTV around 1% compared to optimum value of 4.8%. The low value of this sub-indicator is mainly affected by the overall sub-indicators of the business, which are low in general. The rest of sub-indicators of High Education Institute (HEI), Public R&D (P-R&D), Private R&D (Pr-R&D), and Collaboration R&D (C-R&D) are also less than the optimum value. Since the infrastructure and management sub-indicators affect the R&D sub-indicators as shown in Fig. 3, and since these sub-indicators are low for RTV, the overall sub-indicators of R&D at RTV are also low. The infrastructure indicators should be improved first at RTV since it affects the rest of indicators of Management, Business, and R&D. This can be done by completing the ICT infrastructure, the business and management facilities faster than the current situation.

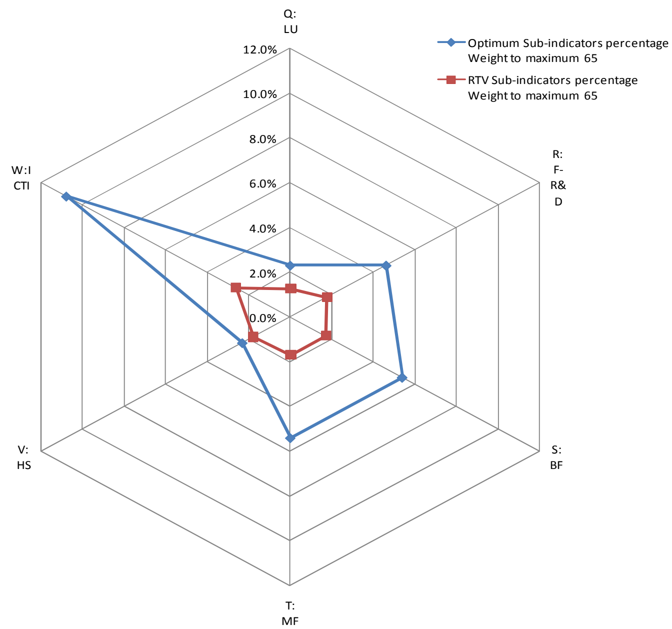

Fig. 7. Optimum performance indicators vs RTV indicators for infrastructure in order to meet RTV Goals

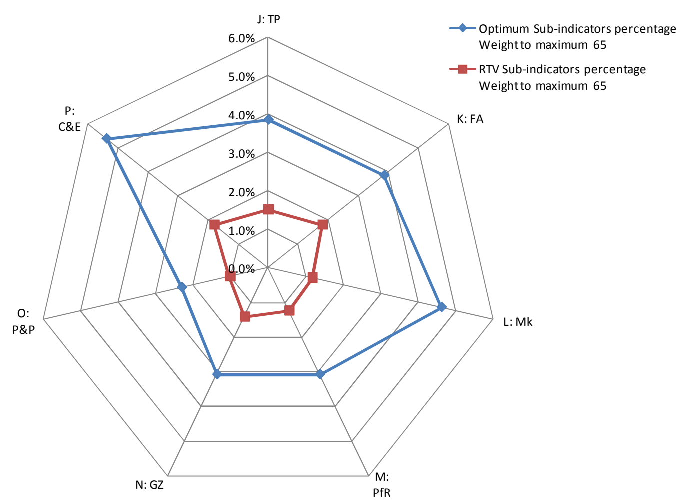

Fig. 8. Optimum performance indicators vs RTV indicators for management in order to meet RTV goals

Fig. 11 illustrates the percentage achievement of RTV goals, where overall achievement reaches 39% at RTV which is not high enough since there are a lot of issues in infrastructure, management, business and R&D that should be addressed as explained before. The best achievement is for goal 1, where 40% of this goal has been achieved so far, and this will improve more once the main issues of infrastructure and business would be addressed and improved. The goals 3 and 4 have the lowest achievement percentage of 38%. This is due to the incomplete Infrastructure which can be used as an excellent environment to attract R&D as well as individual innovators to join RTV. In addition to the low level of sub-indicators in Business and Management which can assist in communicating and attracting individual innovators and R&B private and public sectors to invest at RTV.

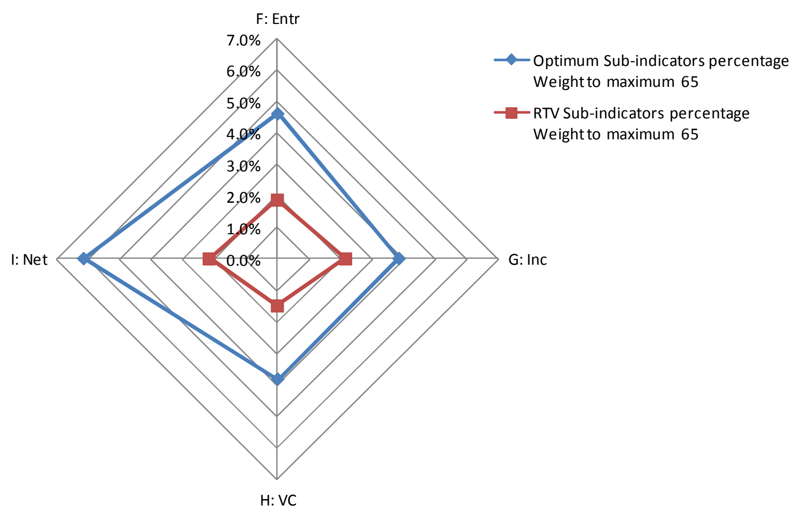

Fig. 9. Optimum performance indicators vs RTV Indicators for business In order to meet RTV goals

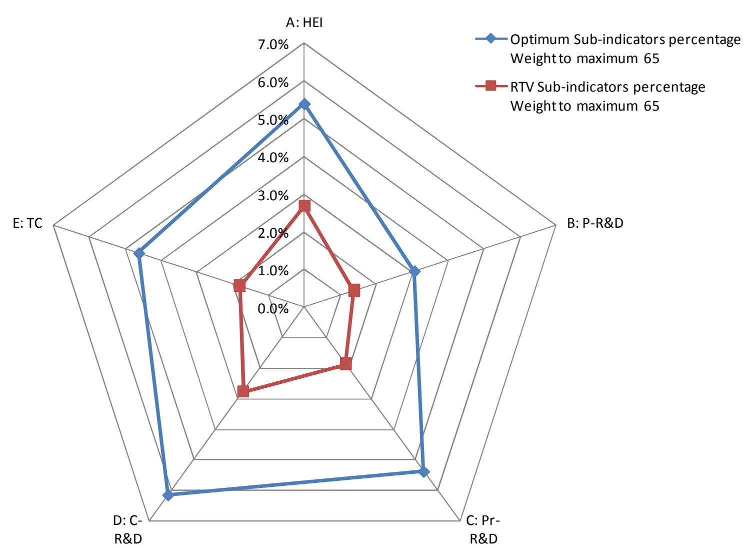

Fig. 10. Optimum performance indicators vs RTV indicators for R&D in order to meet RTV goals

Table 3. Normalization of indicators', sub-indicators' and goals' weights

Indicators		RTV goals				Total sub-indicators weights	Total weights
		1.Transfer & habitat of technology	2. Research collaboration	3. Provide excellent environment	3. Attract innovative and creative persons		
R&D	A: HEI	0.056	0.065	0.051	0.042	0.049	0.259
	B: P-R&D	0.028	0.065	0.026	0	0.027	
	C:Pr.R&D	0.056	0.065	0.051	0.042	0.049	
	D:C-R&D	0.056	0.065	0.051	0.083	0.058	
	E:TC	0.056	0.032	0.051	0.042	0.041	
Business	F:ENTRE	0.056	0.032	0.051	0.042	0.041	0.195
	G:INC	0.056	0.032	0.026	0.042	0.035	
	H:VC	0.056	0	0.051	0.042	0.034	
	I: Net	0.056	0.065	0.051	0.083	0.058	
Management	J:TP	0.028	0.065	0.026	0.042	0.037	0.280
	K:FA	0.056	0.032	0.026	0.042	0.035	
	L:MK	0.056	0.032	0.051	0.042	0.041	
	M:PFR	0.028	0.032	0.051	0	0.025	
	N:GZ	0.028	0.032	0.026	0.042	0.029	
	O:P&P	0.028	0.032	0	0.042	0.023	
	P:C&E	0.028	0.065	0.051	0.083	0.052	
Infrastructure	Q:LU	0.028	0	0.051	0	0.018	0.322*
	R:F-R&D	0.056	0.032	0.051	0.042	0.041	
	S:BF	0.056	0.065	0.051	0.042	0.049	
	T:MF	0.056	0.065	0.051	0.042	0.049	
	U:HS	0.028	0	0.051	0	0.018	
	V:ICTI	0.056	0.13	0.1	0.167	0.103*	
Total sub-indicator's weight/ total goal's weight		1	1	1	1	1	1
Normalized Goals Total weights total goal' indicators weights/ Sum of goals weights		0.28	0.24	0.3*	0.18		

**Most important*

Table 4. Actual RTV performance indicator

	1.Transfer & habitat of technology	2. Research collaboration	3. Provide excellent environment	3. Attract innovative and creative persons	Actual RTV total weights
TAGRATE of each goal	0.090	0.065	0.077	0.037	0.27
Percentage of Normalized RTV goal achievement	32%	27%	26%	20%	27%

Table 5. Actual Assigned RTV's experts' current performance indicators and sub-indicators' levels values with respect to RTV's goal

	RTV current subindicators value as per November 2012 [average of 3 experts]																							
RTV Goals	R&D					Business			Management					Infrastructure									Total Weight	Percentage of RTV Goal achievement
	A: HEI	B: P-R&D	C: Pr-R&D	D: C-R&D	E: TC	F: Entr	G: Inc	H: VC	I: Net	J: TP	K: FA	L: Mk	M: PfR	N: GZ	O: P&P	P: C&E	Q: LU	R: F-R&D	S: BF	T: MF	V: HS	W:ICTI		
1 : transfer & habitat of technology	0.5	0.3	0.3	0.5	0.4	0.4	0.6	0.4	0.4	0.2	0.6	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.2	7.2	40%
2: Research Collaboration	0.5	0.4	0.3	0.5	0.2	0.2	0.3	0.0	0.4	0.4	0.3	0.2	0.2	0.2	0.3	0.3	0.0	0.3	0.3	0.3	0.0	0.6	6.1	39%
3: provide excellent environment	0.5	0.2	0.4	0.5	0.3	0.4	0.3	0.4	0.4	0.2	0.2	0.3	0.4	0.2	0.0	0.3	0.5	0.4	0.2	0.3	0.7	0.5	7.5	38%
4: attract innovative & creative person	0.3	0.0	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.1	0.0	0.2	0.2	0.3	0.0	0.2	0.2	0.2	0.1	0.5	4.5	38%
RTV Overall Sub-indicators Weight	1.8	0.8	1.2	1.8	1.2	1.3	1.4	1.0	1.4	1.0	1.4	0.7	0.8	0.8	0.7	1.2	0.8	1.2	1.0	1.1	1.2	1.8	25.3	39%
RTV Sub-indicators percentage Weight to maximum 65	2.7%	1.2%	1.8%	2.8%	1.8%	2.0%	2.1%	1.5%	2.2%	1.5%	2.2%	1.1%	1.2%	1.2%	1.0%	1.8%	1.2%	1.8%	1.5%	1.7%	1.8%	2.8%	38.8%	39%
RTV current value of sub-indicators (Normalized to optimized ICTI)	25%	11%	16%	26%	16%	19%	19%	14%	20%	14%	20%	10%	11%	11%	9%	17%	11%	17%	14%	16%	17%	26%		

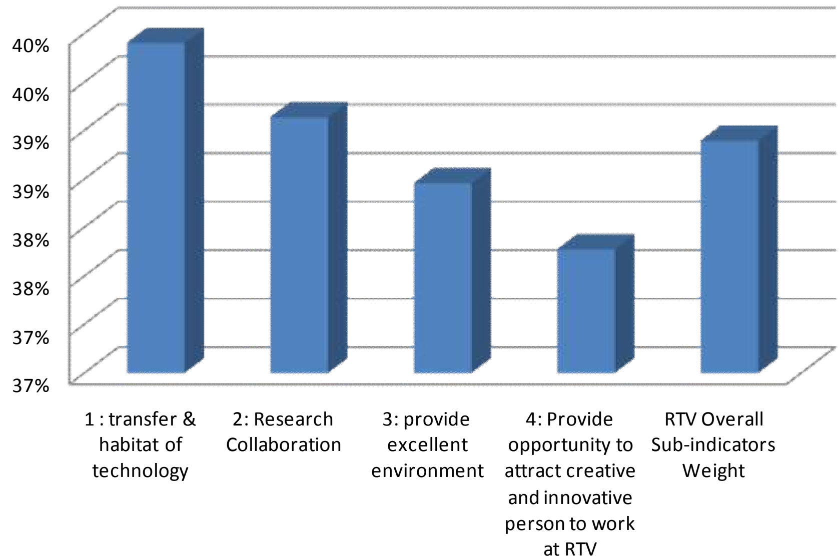

Fig. 11. Percentage achievement of RTV goals

6. CONCLUSION

The concept of measuring the effectiveness of SP in relation to its goals has been presented. A proper eco-system plays an important role in creating innovation, where SP is the major party of this system. Achieving the main goal of SP for developing a strong knowledge based economy, can be done through an effective knowledge transfer and creation, a good knowledge sharing using latest technologies and successful collaborative platform strategies, a good utilization of knowledge through applying different initiatives for the successful of transfer and habitat of technologies, as well as the use of effective knowledge measurement using a novel analytical approach. Unlike the descriptive approach used in other references for checking the organization's readiness in order to identify the gap and try to fill in this gap, a better method using analytical approach called goal-based key performance indicator mechanism has been suggested in this paper. This new method for measuring the effectiveness of Science Park and its knowledge-based economy has been presented. This is based on quantitatively analytical approach by identifying the optimum value of the pre-defined sub-indicators in order to achieve the Science Park goal. Then this study identifies the real value of these sub-indicators in relation to the goals of Science Park using survey forms that has been filled in by experts. This will allow manager to compare the real sub-indicators values of their Science Park to the optimum ones in order to identify the gap. It uses different key performance sub-indicators that are associated with four groups of R&D, Business, Management and Infrastructure. These performance indicators are assessed in relation to the goals of an organization by estimating their optimal achievement values. The actual performance of RTV has been compared to the estimated optimum performance indicators in order to determine the gap and suggest improvement. The actual overall performance was about 27 %, or (0.27). Due to the inherent uncertainty in the experts' judgment, this study has formulated an overall measure to assess the overall performance and we have established psychometric fuzzy scale to measure the actual against the optimal overall performance. The proposed assessment will be used to monitor, control and guide improvement of the SP' performance. A comparison between the actual overall performance of sub-indicators of RTV and the optimum values has indicated that the level of overall performance of the RTV SP is "Low", according to the developed fuzzy assessment scale.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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