A Business Intelligence Architecture To Monitor And Analyze National Science And Technology Developments

Abbas Keramati
School of Industrial Engineering
College of Engineering, University of Tehran
Tehran, Iran
keramati@ut.ac.ir

Vahid Khatibi
School of Industrial Engineering
College of Engineering, University of Tehran
Tehran, Iran

Abstract—Business intelligence (BI) assist organizations assess their performance through integration of various data resources as one of fundamental pillars in national development of countries, and governments devise appropriate policies to flourish their national S&T developments. In this paper, a BI architecture for integration of national S&T data is proposed to assess and analyze national S&T developments. For this purpose, first the performance management cycle of national S&T developments is designed, and then to materialize this cycle, the BI architecture for monitoring and assessment of national S&T developments is proposed. In a case study on the national Iranian S&T data resources, the proposed architecture is used in developing a prototype system to evaluate its effectiveness in practice. The developed system provides S&T policymakers with a holistic macro-level view of nationwide S&T development trends which help them propose appropriate policies.

Keywords—*Business intelligence; Performance assessment; Science and Technology; Science policy; S&T indicators words*

I. INTRODUCTION

Fundamental changes outbreak in global arena such as rapid rate of changes and increasing of complexity have transformed management of organizations, and novel mechanisms should be used to cope with these changes. Hence, improvement of flexibility to adapt with changes to measure and analyze performance indicators. On the other hand, science and technology (S&T) are considered has prior importance in agile organizations, and they try to augment their capabilities to encounter new changes [1, 2]. On the other hand, development of information technology (IT) infrastructures have brought vast volume of various information, so as accomplishment of organizational missions depends on efficient usage of these information [3]. Hence, information resources management plays a critical role in organization success, and attention to effective information processing and analysis is necessary [2]. In this way, comprehensive, pervasive and real-time information flow in organization is considered as one of the key success factors [4, 5]. Also, transformation of information to knowledge and its efficient use are primal compartments in decision-making process, because quality of organization's decisions depends on available knowledge which in turn provides organization with the ability to adapt with changes [6]. So, effective utilization of information technology capabilities in data gathering, knowledge creation and support of decisions is inevitable [7, 8]. Recent studies and researches have recognized business intelligence (BI) as the best solution to comprehensive and pervasive information analysis problem

[9, 10]. BI can be interpreted as a continuous cycle for performance management by which an organization determines goals, analyzes progress, acquires insight, takes actions, and measures success [10, 11]. For this purpose, identification of information needs, processing of gathered data and their transformation to useful knowledge for application in decision-making process should be pursued. Also, BI facilitates performance management in organizations through applying appropriate tools such as key performance indicators (KPIs) and score cards to measure and assess organization success in its missions [12].

Business intelligence can be considered as the combination of business processes with the IT systems such as data warehouses, data marts, meta-data data mining, query and reporting software, and visualization to support decision-making in an organization [13, 14]. Also, an ideal BI system gives an organization's employees easy access to the information they need to effectively analyze the data and information to gain critical insight that helps the organization make informed decisions. Therefore, BI is a continuous and systematic process by which an organization acquires, analyses, and disseminates relevant business data and information to turn them into usable knowledge and intelligence [15, 16]. The effective implementation of business intelligence brings an organization several advantages such as improving the quality of strategic and operative decision-making, more systematic information need analysis, and faster decision-making processes achieved by relevant and timely intelligence [17, 18].

On the other hand, because of science and technology (S&T) importance in national progress of countries, governments invest heavily on planning and management of S&T environment to augment their competitiveness power in international level [19]. We mean national S&T developments as accomplishment of national goals, missions and plans in S&T area which includes all the scientific and technological programs aimed in national level. Regularly, national S&T programs are planned according to national necessities and capacities, and then, their execution and accomplishment are monitored [20, 21]. Also, governments have implemented policies to enhance S&T capabilities as a means to ensuring their economies' competitive ability [22, 23]. In addition to increasing innovation significance in socio-economic development, the need for utilizing prospective-oriented information in innovation policymaking is growing. Scientific and technological development decision-makers need all-inclusive information about current situation, and also future developments of society, economy and impacts of science and technology, so as such information is important for comparing the innovation performance of nations to other economies [24, 25].

Since there are several and diverse information resources in S&T area, they should be integrated to monitor and analyze the national S&T developments. Also, qualified information should be prepared for the monitoring, whereas initial raw data have not ready for this purpose, and they should be processed and summarized to be useful in decision-making process. Hence, proposing a BI architecture is an appropriate solution to strength the effective analysis of massive S&T information to monitor the national S&T developments through comprehensive integration of various information resources, summarization of vast information, extraction of qualified information and accelerating the access speed to analyzed information which in turn provide national S&T policy-makers with correct and rapid perception of change trends, and support of their decision-making. In this paper, a BI architecture for the management of S&T information to measure and analyze the national S&T developments is proposed and discussed.

The remainder of this paper proceeds as follows. After introducing the performance management of S&T developments in Section 2, the business intelligence concept has been discussed in Section 3. Then, a BI architecture for the national S&T monitoring and trend analysis is proposed in Section 4. Based on the proposed architecture and in a case study on the national Iranian data resources, a prototype system is developed to evaluate its effectiveness in Section 5, and at last, the research implications is discussed in Section 6.

II. PERFORMANCE MANAGEMENT OF S&T DEVELOPMENTS

Whereas in almost most researches and practices, the performance assessment is accomplished enterprise-wide [9, 26], the studied scope in current research is nation-wide, so as it includes national global scale which means all the foundations and institutions regarding the national S&T developments. Therefore, instead the enterprise performance assessment, the national S&T performance assessment is interested. Hence, the proposed BI approach to monitor the national S&T developments is capable to assess the whole national S&T system including universities and R&D institutions. For this purpose, best practices of the BI approaches to performance assessment has been studied, and then, according to special considerations of national S&T developments, the appropriate and comprehensive BI model for its monitoring and trend analysis has been represented. Policymakers of the national S&T programs can exploit the proposed approach to monitor the national S&T developments based on the measurement and analysis of S&T indicators [19]. Therefore, the national S&T status is assessed and monitored continuously which provides national S&T policymakers with exact information describing national S&T area that can be used in proposing appropriate national S&T policies [27].

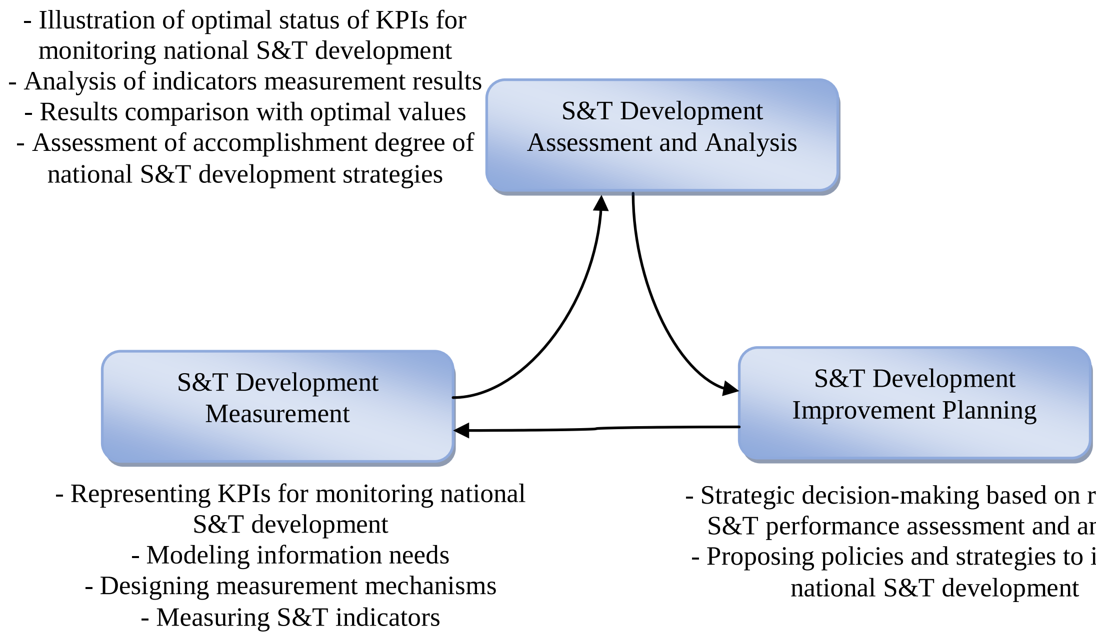

Fig 1. S&T development performance management

Since BI can be considered as a continuous cycle of performance assessment to determine goals, analyze progress, acquire insight, take actions and measure success [10], applying BI approach to manage the national S&T information can be formulated based on elements of the performance management cycle (Fig. 1) as follows:

A. *S&T Development Measurement*

This element includes representation and definition of key performance indicators for monitoring national S&T

development, modeling information needs, designing measurement mechanisms, and at last measuring the S&T indicators.

B. S&T Development Assessment and Analysis

This element includes illustration of optimal status of key performance indicators for monitoring national S&T development, analysis of indicators measurement results, comparison of the results with optimal values, and assessment of accomplishment degree of proposed strategies for national S&T development.

C. **S&T Development I*mprovement* Planning**

This element includes strategic decision-making based on the results of S&T performance assessment and analysis to improve national S&T development through proposing appropriate policies and strategies.

Hence, designing and implementation of aforementioned cycle and subset components of its elements using BI capabilities provides us with the main core of national S&T development assessment. According to this basis, the essential guidelines which should be addressed are represented in three phases in following:

First, the BI role and functionalities in S&T information management and S&T development monitoring should be determined, so as information needs which BI can respond to and the appropriate process model of BI application in measurement and analysis of S&T indicators should be studied.

Second, the national S&T development monitoring linkage to a set of key performance indicators to assess and analyze national S&T area should be determined. For this purpose, mechanisms that BI facilitates the S&T indicators measurement and analysis should be designed. Also, representation methods of S&T development assessment and analysis results for S&T policymakers should be proposed.

Third, strategic decision-making of national S&T development should be aligned with measurement and analysis of S&T indicators. Therefore, the optimal trajectories for national S&T development should be identified based on alignment of the measurement and analysis results with national S&T development strategies. Also, the trends of national S&T development can be led to optimal ones through proposing appropriate policies.

III. BUSINESS INTELLIGENCE

Business intelligence improves business performance by making actionable information available for decision-makers in an organization [16,26,28]. The term intelligence can be defined as a collection of information pieces that have been filtered, analyzed, and turned into knowledge, understanding, and deeper insights. Thus, intelligence is value-added information that can be acted upon [15]. Business intelligence systems have the potential to maximize the information use by improving the capacity of organization to structure a large volume of information and make it accessible [10], thereby creating competitive advantage, what Davenport calls ‘‘competing on analytics” [29].

Business intelligence integrates data and information from various data sources using the extract, transform and load (ETL) process to extract transactional data, transform and upload data into data warehouses. Then, data mining tools such as online analytical processing (OLAP) and ad hoc query operate on the vast amount of information stored in the data warehouses or data marts to produce business related reports in a timely (near real-time) and friendly format [30-32]. Also, the business intelligence is an umbrella term encompassing a broad range of concepts, processes, methods, techniques and tools for gathering, consolidating, analyzing and providing access to information to improve business decision-making [33-35].

A literature review on business intelligence distinguishes two broad technical and managerial approaches towards this concept. The managerial approach considers BI as a process in which data gathered from internal and external sources are integrated in a centralized data repository in order to generate actionable information suitable for decision-making process via BI analytical tools [32, 36, 37]. By actionable information, we mean information that enables organizational members to make informed choices about important practical problems. Hence, creation of an information platform to gather and analyze operational data from transactional databases to disclose strategic business patterns is the main role of BI in the managerial approach [38-40]. The technical approach considers BI as a set of tools and techniques which support the process of extracting, manipulation and analysis of information [13, 34, 41], and introduces it as a data-driven decision support system [42, 43]. Convergence of various BI technologies such as data warehousing, data mining and OLAP to establish a single integrated architecture is an essential issue in the technical approach [44-46].

Although there are differences between technical and managerial approaches to BI, they agree on two issues: first, the BI core is gathering, analysis and distribution of actionable information, and second, the BI main goal is supporting the strategic decision-makers. By strategic decisions, we mean decisions relevant to evaluation and change of organizational vision, mission, goals and objectives that usually have medium- to long-term impacts on the organization, in contrast to operational decisions that are day-to-day in nature and more related to execution [10]. The literature review depicts that advances in the technical approach of BI have been greater than the managerial one. Despite increasing the available volume of information in technical approach such as data warehouses and analytical tools, this does not directly imply that organizations or individuals have ability to utilize them [47].

IV. NATIONAL S&T BUSINESS INTELLIGENCE ARCHITECTURE

Based on the conceptual framework proposed in Section 2, business intelligence has been used to materialize national S&T performance assessment. For this purpose, business intelligence architecture for national S&T monitoring and trend analysis is developed in a layered structure, as shown in Fig. 2. The proposed BI architecture integrates S&T data from heterogeneous data resources using the extract, load and transform (ETL) process into a data warehouse, and then, analytical tools operate on the comprehensive data stored in the data warehouse to produce reports for S&T policymakers in a timely and friendly manner. The proposed BI architecture consists of five layers including S&T data resources layer, S&T data conversion layer, S&T multi-dimensional data warehousing layer, S&T monitoring and trend analysis layer and S&T actionable information representation layer which have been described in following.

S&T data resources layer comprises of the transactional databases where raw S&T data are stored. Data resources can be internal or external such as interior databases of an S&T assessment organization and exterior databases of the Ministry of Science, respectively. Hence, overall data pertaining to the national scientific and technological activities are accumulated in the data resources layer. In order to design S&T databases, we need data modeling using entity relationship model (ERM) and normalization approach to ensure that the databases' entities are normalized to the third normal form which in turn is essential to prevent data inconsistency, redundancy, and anomalies that reduce the data quality, complicate ETL process, and result in poor quality BI system.

S&T data conversion layer consists of extract, transform and load tasks of the S&T data from heterogeneous data resources into the data warehouse. The extract task acquires all the required data from transactional databases, and then the transform task maps the data into an appropriate format for the data warehouse. At last, the load task transfers the transformed data into the data warehouse. The S&T data conversion layer design begins with identification of the data that need to be extracted, the data quality and additional information necessary to provide complete and meaningful information. Also, reconciling the data redundancy, and cleansing the dirty data found in the resources should be followed during the S&T data conversion layer design.

The S&T multi-dimensional data warehousing layer can be considered as the comprehensive S&T data agglomeration center of the national S&T monitoring BI architecture where the data warehouse is required to be designed and developed. In fact, all the gathered S&T data from various S&T data resources should be integrated in the comprehensive multi-dimensional data warehouse. Before designing the data warehouse, it is important to

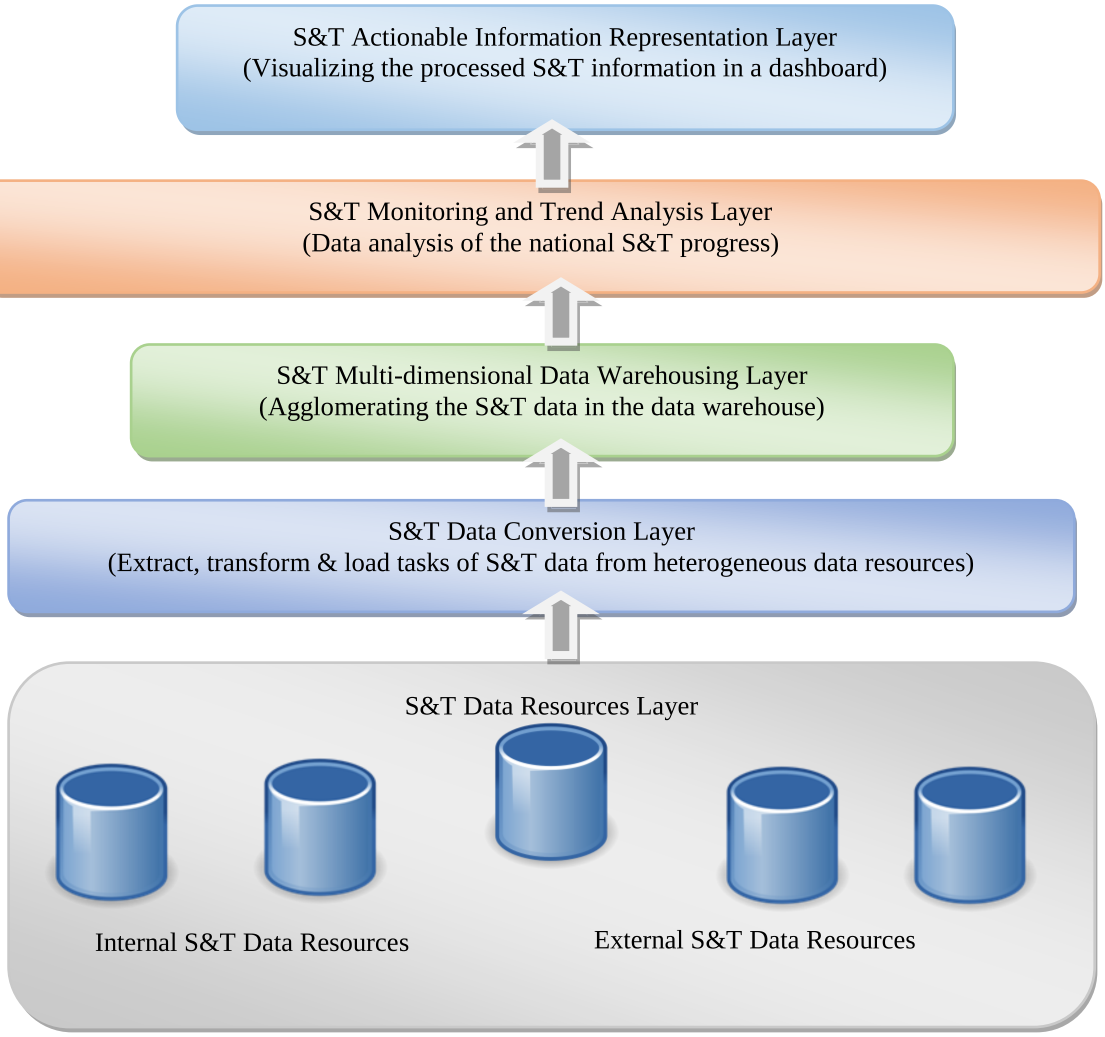

Fig. 2. The national S&T monitoring and trend analysis BI architecture

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determine the data warehouse's specific technical and functional requirements.

The S&T monitoring and trend analysis layer of the national S&T assessment BI architecture concentrates on the development of mechanisms and algorithms to monitor and analyze the trends of national S&T progress. The logical view of the entire national S&T indicators interrelationships, business logic and rules governing the system all fall within this layer. Hence, the complex data mining analysis is performed in this layer, so as various techniques of reporting and forecasting can be used to generate summary processed information suitable for decision-making regarding specific S&T objectives.

The S&T actionable information representation layer can be considered as a comprehensive dashboard where processed and actionable information is visualized by reporting tools in forms of tables, charts, gauges, etc. Strong graphical capabilities have been used to better render and illustrate results for different queries of the S&T-BI end users.

V. Case study: Applying proposed architecture to national Iranian S&T data resources

The developed prototype system provides a global snapshot of the national S&T environment including capacity and outputs through performing numerous analyses. For this purpose, interactive reports of bar charts, pie charts, radar diagrams, bubble charts and gauge charts have been used in the comprehensive dashboard. The reports are linked together using the fields in common so that a filter applied on a report updates all linked reports. Also, the dashboard supports drill down functionality in many reports, so as a particular dimension can be selected to disaggregate the information further. Filters are available as lists, drop down items, sliders and search boxes. In the following, the prototype system has been applied to the Iranian S&T data resources, so as the versatile capabilities of the proposed system have been demonstrated, along with illustrating the findings derived from analyzing the Iranian S&T data resources.

As shown in Fig. 3, one of the S&T-BI dashboards consists of five reports on S&T human resources. The first report is a bar chart, illustrating the total research personnel of the state, second, a line chart exhibiting total research personnel per million populations, and third, a pie chart showing distribution of research personnel in institution types. Also, fourth and fifth charts are bar chart of research personnel groups and combo chart of total research personnel and researchers per million populations, respectively. Filters on top of the dashboard provide users with control on reports.

The S&T human resources analysis depicted that the number of S&T personnel has been increasing during the past years. Also, the number of researchers per million populations has taken a growing trend. It has grown on average by 12.4 percent in the studied period, comparing this figure with the national annual population growth of 1.6, it is expected that the share of researchers of the population will reach to salient proportions in the next years. Also, the most researchers have been in the engineering and humanities fields, so as the basic sciences field has had the least researchers among subject areas (Figure 4-a). The distribution of S&T human resources in the national provinces has been highly unbalanced, so as almost 37 percent of the research personnel have been working in Tehran province. In comparative study of the provincial S&T personnel, dramatic divide can be observed among the provinces (Figure 4-b), indicating the unbalanced distribution of the S&T resources and facilities at the national level. This issue implies that the national S&T policymakers should pay attention to investment and proper distribution of the research human resources among the less developed provinces.

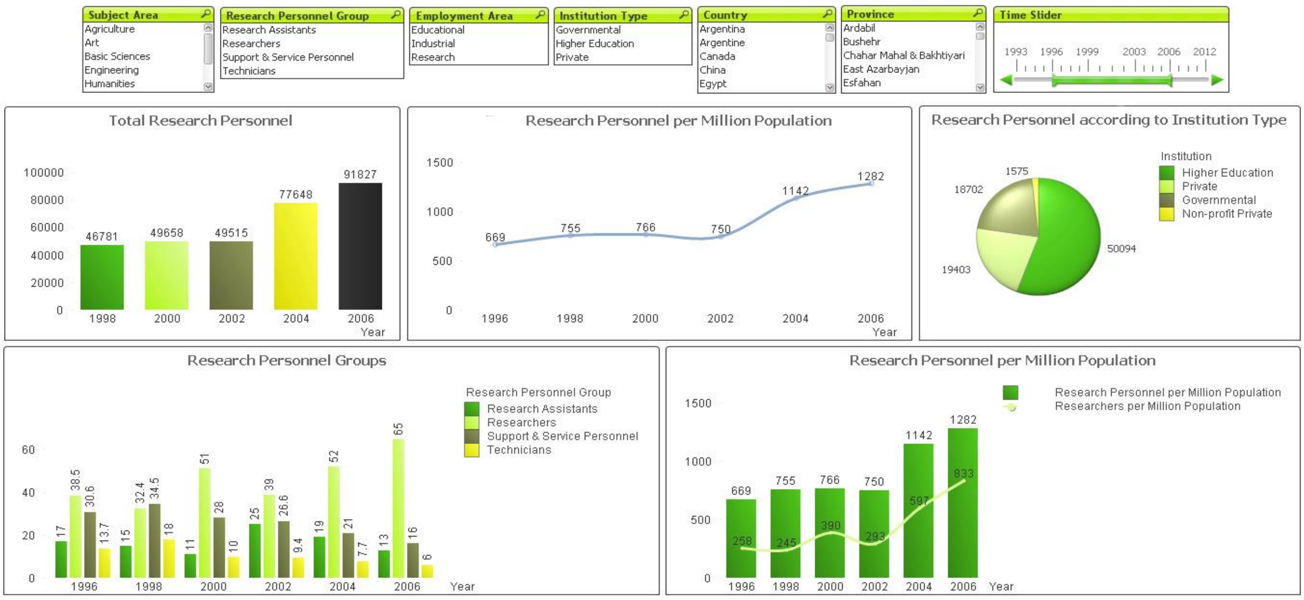

Fig. 3. The prototype system dashboard for the national S&T performance assessment; consisting of five reports on S&T human resources and a group of filters

The national research personnel by sector of employment, including research, industrial and educational sectors, has had a bias towards the educational and research sectors, so as these sectors have contributed to the whole S&T manpower by 49 and 34 percent, respectively, and the industrial sector share has been only 17 percent (Figure 4-c). Since the research plans play an important role in the improvement of production process, and quality of products and services in the industrial sector, inclusion of only 17 percent of the national research manpower in the industrial R&D sector implies the research activities weakness in the industrial sector. Taking into account the above statistics, it is clarified that the industrial sector has paid lower attention to the research in comparison with the educational and research sectors, so as this factor can be mentioned as one of the main reasons for the weakness of the national industrial development in Iran.

VI. Discussion

For performing the aforementioned analyses, appropriate fields have been acquired from the dimension and fact tables through using the star schema. These reports can support policymakers in identifying the particular areas which are in need of more attention, while the complexity of calculations and database queries have been kept behind the scene and the system users are able to exploit filters and sliders to perform various analyses to study the national S&T progress trends. In this way, the proposed system revealed that there are potentially suitable human resources and facilities for improving the national science and technology in Iran.

The national achievements so far have been satisfactory; nevertheless, when compared with other nations, it is found out that Iran is still far behind successful countries and even the average international level. Iranian researchers still play a marginal role in the scientific publications of the world, particularly in non-

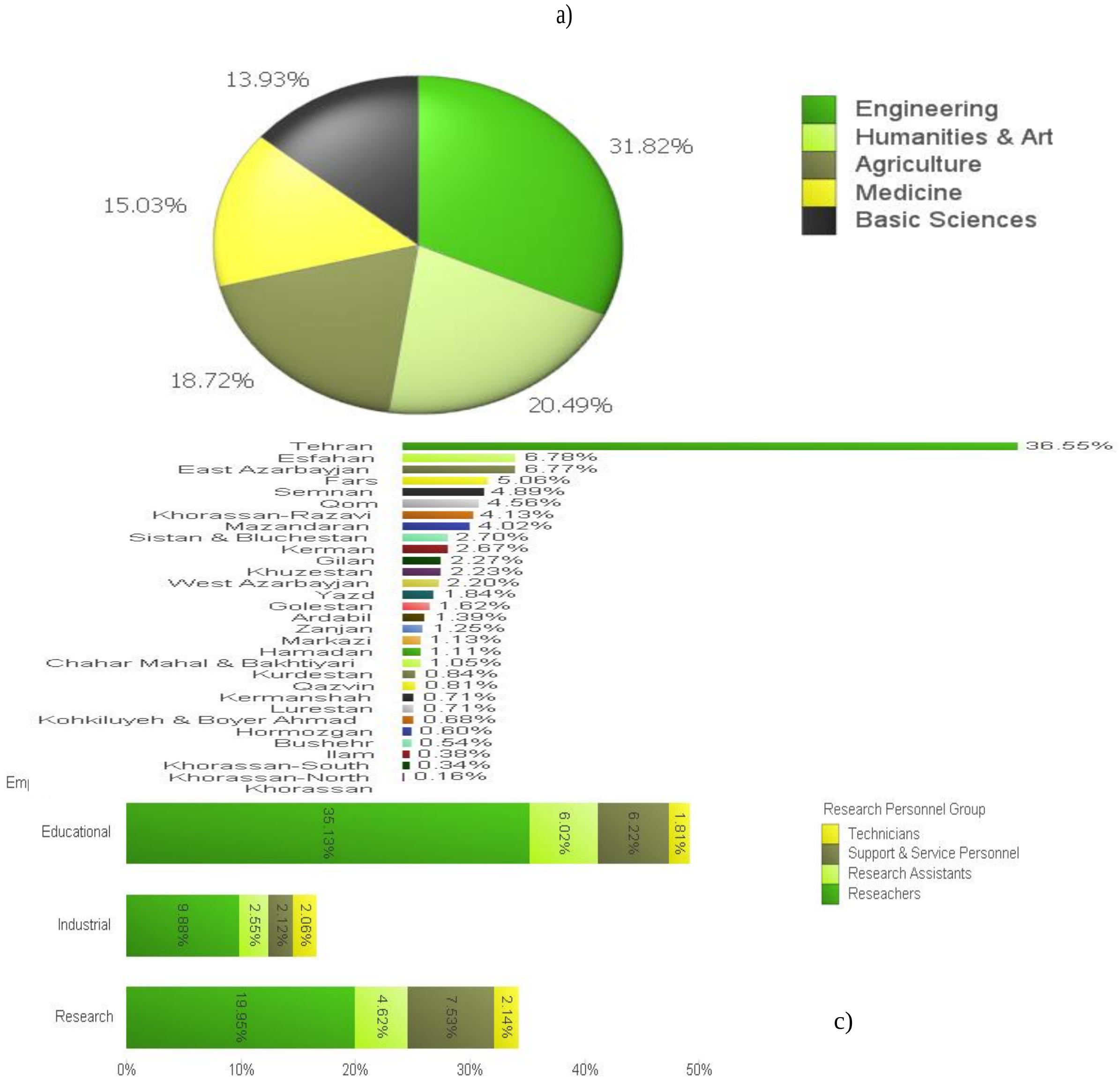

Fig. 4. Some of the national S&T human resources indicators in the S&T-BI system;
a) Researchers in subject areas, b) Provincial research personnel, c) Research personnel by employment sector

applied and non-experimental sciences. Nonetheless, some of the national S&T indicators have rapidly improved in recent years. At the moment, Iran has a better condition in the creation of scientific knowledge compared to the past. Despite all these, low consistency is observed in the perspective of aligning scientific research to the social and industrial needs in Iran, due to the unavailability of promising stimuli and motivating forces. Although there are some indications that the quality of Iranian scientific production has increased, there is still more emphasis on the quantity rather than the quality. Regarding technology and innovative use of scientific findings, there has been found a large divide between Iran and the developed nations.

VII. Conclusions

Because of BI capabilities in gathering, monitoring and analyzing vast and diverse information, and also facilitating the decision-making process, foundation of the proposed approach in this paper is based on BI to gather, monitor and utilize the S&T information to measure and assess the national S&T developments. The performance management cycle of S&T developments was designed to be the main core of performance assessment in the proposed approach. Then, a business intelligence architecture is proposed to materialize the S&T performance management cycle. In a case study on the national Iranian data resources, the proposed architecture has been evaluated. National S&T policymakers can exploit the proposed architecture to monitor and analyze the whole national S&T trends which assist them to propose appropriate policies.

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