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Full Length Research Paper

Reverse analytic hierarchy process (AHP) to prioritize emerging IT technologies: A case study in Korea IT industry

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This study aims to present prioritization judgment method for emerging IT technology selection in accordance with the analytic hierarchy process (AHP) methodologies. Emerging technology selection is an activity aimed at efficient investment of limited national resources. However, the term 'emerging technology' in itself is inundated with the uncertainties of the future. Moreover, as with other selecting techniques, it is not easy to judge the results of selection made through AHP prioritization method for emerging technology, which is the core argument of this study. Accordingly, this study presents reverse AHP (RAHP) methodology as an enhanced judgment method for selection of emerging technology case study in Korea IT industry.

Key words: Emerging IT technology, judgment and selection, analytic hierarchy process (AHP), reverse AHP (RAHP).

INTRODUCTION

Many nations have invested financial and human resources in emerging technologies for a few decades as technologies become more important to ensure a nation stay competitive in the world market. IT industry has recently been experiencing rapid growth. Therefore, verification of forecasting technology is significant since a lot of time, effort, and financial costs were being invested in selecting the most promising technologies. In order to effectively structure Research and Development (R&D) expenditure and to determine the priorities in the research areas, many countries are implementing national forecast projects with the goal of determining key technologies and research directions of the country.

The Korean government's assiduous support for the heavy and chemical industry sparked a remarkable growth of the IT (electronics) industry. The development of the IT industry elevated the status of Korean manufacturing sector to a whole new level by boosting the competitiveness of Korea, which severely lacks in natural resources. The current buzz word in the global IT market is "Fusion and Convergence." This refers to the convergence and cooperation of technologies in order to induce rapid technological changes, and this requires decisions on efficient allocation of limited amount of resources.

Only a few of countless number of new technologies emerging in the world survives or grows rapidly in the market. Dramatic evolution, competition, survival, growth, decline and disappearance of these next-generation technologies do not merely represent a life-cycle of any technology. Rather, such process requires the society to make choices that may elicit social cost that may results in high risks. Under these circumstances, constraints on resources require a nation to draw on the strategy of "Selection and Focus" in order to secure crucial technologies. That is why Korea, as well as other advanced countries with cutting-edge technologies, is eager to make an efficient use of the national resources and to be a step ahead in competition for new technologies. This research aims to identify potential technologies for the Korean IT (electronics) industry and conduct an empirical study to evaluate and judge these technologies, in response to the trend of "Fusion and Convergence" in the global IT industry.

This study suggests the research on usefulness of application of analytic hierarchy process (AHP) methods on the results of emerging technology selection. Unfortunately, there is no way of making proper judgment solely by general AHP methodology. So, the results of prioritization of diverse range of technologies through reverse AHP (RAHP) methodology will be judged by using the Bayesian concept that can reduce the limit of generation of statistical error of AHP methodology. Reverse AHP refers to a careful re-inspection or re-examination to assure accuracy or proper condition, that is, evaluation. Moreover, reliability of judgment based on how the selected emerging technologies, through AHP methodology along with reverse AHP (RAHP) by research institutions that carry out emerging technology selection, have been applied to the R&D activities following technological choice will be looked into. RAHP methodology is more meaningful as it develops a judgment process on the results of prioritization of technology and compares such results against actual case study in order to find out the rate of success in identification of potentially promising technologies.

LITERATURE REVIEW

Multi criteria decision making (MCDM) for emerging IT technologies

Decision-making process on which method among various alternatives and under what circumstances to be chosen in having to make selection of emerging technology among countless number of IT technologies differs according to the given environment. In general, judgment refers to quantitative, order or categorical evaluation made under the present situation, and judgment is always involved in process of decision-making (Stevenson et al., 1990).

Stevenson et al. (1990) and Kleindorfer et al. (1993) defined decision as making selection among various alternatives that will bring about results with some desired value to the decision maker. In addition, there are cases in which the possibility of occurrence of results of decision is certain and cases in which it is uncertain. Furthermore, there are situations in which the results that can be produced or what usefulness can be acquired may be uncertain, without uncertainty on how satisfactory the results of the actions one has chosen to take.

In particular, “focusing and selecting” emerging technology at national level by finding them among diverse and countless number of IT electronic technologies with different technological levels and market entry times is a very difficult decision-making process when considering the future uncertainties and from the perspective of risk management. In order to reach an optimum decision, well-defined criteria and solution techniques are required. Selection should also be based on extreme conditions rather than average normal conditions. Multi criteria decision making method (MCDM) is a systematic method of selecting the optimal alterative for the complicated problem that cannot be approached easily under uncertain situation (Oh, 2009).

Tam et al. (2004) is incongruous with the basic MCDM logic because of the fact that MCDM is a useful and reasonable device employed when there are little differences between the characteristics of alternatives and thereby making the selection process a tough and indecisive work. With regards to theoretical approach to MCDM among the MCDM methods and tools, several approaches and theoretical disciplines can be defined, although their distinctions and boundaries are often difficult to determine. This discussion adopts the classification of MCDM approaches proposed by Pardalos et al. (1995). In the meantime, Montgomery (1989) proposed group decision-making as the most effective method when there is a large quantity of qualitative/quantitative data. From this perspective, the AHP is the most representative methodology among the MCDM tools.

Understanding of AHP and RAHP

Analytic hierarchy process (AHP)

AHP is a powerful management research tool that was first developed by Saaty (1971). IT has been a tool used by decision makers and researchers; and it is one of the most widely used MCDM tools. Its validity is based on thousands of actual applications in which the AHP results were accepted and used by the decision makers (Szczypinska and Piotrowsk, 2008; Tzeng et al., 2002; Wu et al., 2007). AHP is designed to solve complex multi-criteria decision problems. It is a flexible and powerful tool for handing both qualitative and quantitative problems. The AHP approach has been adopted in many applications including project selection (Mustafa and Al-Bahar, 1991) and business performance evaluation. Additional application areas include problems in public policy, marketing, corporate planning, procurement, etc. (Saaty, 1994).

Figure 1 displays the general hierarchical structure of AHP which are composed of 4 steps: first, state the problem and broaden the objectives of the problem or consider all factors, objectives and its outcomes. Second, identify the criteria that influence the behavior. Then, structure the problem in a hierarchy of different devices constituting goal, criteria, sub-criteria and alternatives. Third, compare each element in the corresponding devices and calibrate them on numerical scale. This requires $n(n-1)/2$ comparisons, where n the number of elements with the considerations that diagonal element are equal or ‘1’ and the other elements will simply be the reciprocals of the earlier comparisons. Fourth, perform calculations to find the maximum eigenvalue, consistency

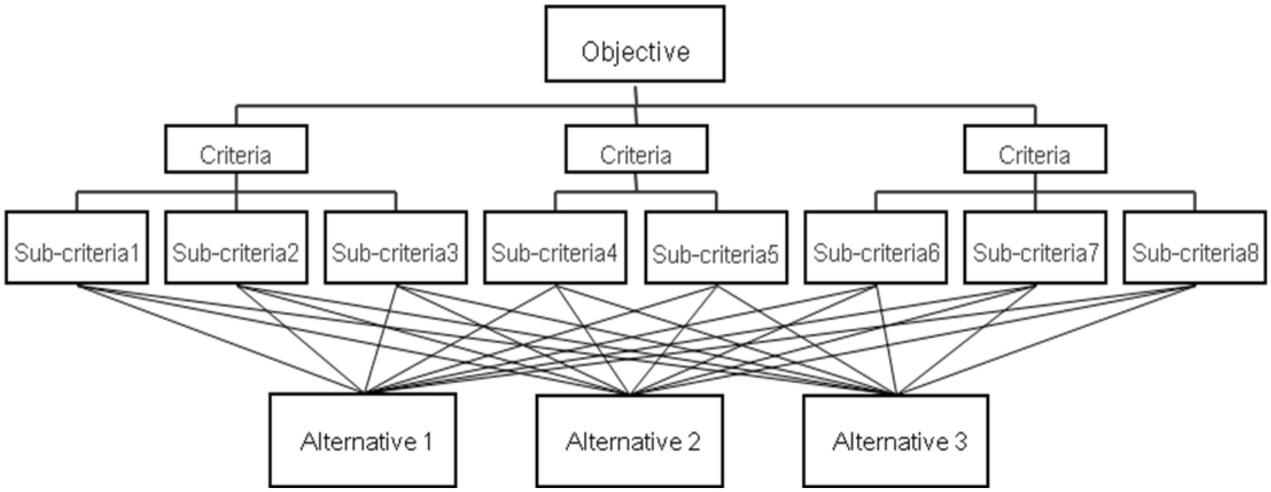

Figure 1. The hierarchy of the general AHP model.

index (CI), consistency ratio (CR), and normalized values for each criterion/alternative. To measure the consistency of the respondent's judgments, AHP uses CR. The consistency of the judgment can be determined by a measure called the consistency ratio which is defined as:

$$CR = \frac{CI}{RI} \tag{1}$$

Where CI is the consistency index and RI is the random index. CI is further defined as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

Where RI is the consistency index of a randomly generated reciprocal matrix from the 9-point scale with forced reciprocals. If the CR of the matrix is high, it means the input judgments are not consistent and hence are not reliable. In general, a consistency ratio of less than 0.1 and in the range of 0.10 to 0.20 is considered very acceptable and acceptable, respectively. If the value is higher than 0.20, the judgments are not reliable and have to be elicited again (Saaty, 2000). Consequently, if the maximum eigenvalue, CI, and CR are satisfactory, then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range.

Reverse AHP (RAHP)

Reverse AHP method begins with Bayesian concept. We have introduced Bayesian concept for re-prioritization of AHP. Originally, Bayesian concept began with Bayes' theorem, one of the main tools for manipulating probabilities; it is applicable no matter what interpretation is being placed on the probabilities being manipulated. Bayesian inference is a formal approach to making statistical inferences in cases where some of the probabilities are interpreted as representing beliefs, or knowledge, rather than having a frequency-based interpretation. It shows two conditional probabilities which are reverse of each others.

AHP can affect the decision-making of the responders of the examination as the number of comparison factors increase. Therefore, AHP is often introduced to recover the cause from statistical experiments. The RAHP which uses the general AHP for implementation of the single criterion s1, and then the hierarchy inversing of general AHP for decomposing s1 into sub-criteria (like as c1, c2, and c3). The methodology of RAHP itself is not literally new in literature but quite useful in prioritizing emerging technologies for country-level R&D resources allocation.

Basic hierarchy of RAHP is composed of total of 3 levels, namely, the goal, the states of nature (Θ) and the outcome of the experiment (X). Moreover, comparative evaluation and verification with the resultant values of general AHP is carried out by using the value of the state of nature (Θ) through reverse of the original hierarchy of AHP (including subordinate hierarchy). For the technology A selected by the regular AHP (Δs), RAHP directly estimates:

$$P(c1|A), P(c2|A), P(c3|A) \tag{3}$$

Where, P (c1) is a c1 from technology A. RAHP is a kind of evaluation method for results of regular AHP through utilization of three alternatives, namely, c1, the technical, c2, the strategic, and c3, the economical alternative.

Prioritization method is in accordance with RAHP methodology of prioritizing the extent of matching by mutually comparing the resultant values of RAHP (Δ_b)

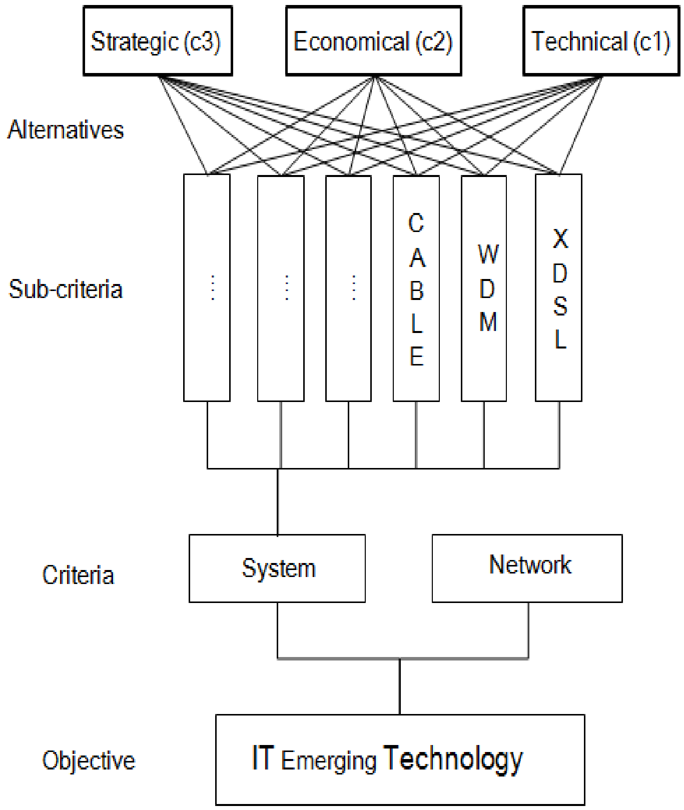

Figure 2. The hierarchy of reverse AHP (RAHP).

with those of the general AHP (Δ_s) in the method similar to that of RAHP for various priorities acquired through general AHP analysis. Illustration of brief summary of hierarchy of RAHP is given in Figure 2.

In its simplest form, this type of dependence involves reverse of a hierarchy (turning it upside down) and evaluating the states of nature in terms of outcomes, which is precisely the reverse of what we would have done in the general AHP (that is, finding priorities of outcomes in terms of the state of (nature). RAHP model provides a natural framework for the application of both inference processes regarding the parameters of a given general AHP model, as well as of model selection itself, incorporating the associated uncertainties (Bernardo and Smith, 1994).

Reverse AHP (RAHP) is proposed to reduce statistical error in the responders that frequently occur in general AHP when there is large number of pair-wise comparison subjects. The Bayesian approach also makes it possible to consider another kind of information issued by decision makers. Here, RAHP methodology will be briefly consolidated as a type of re-examination for prioritization on general AHP. Computational formula for RAHP prioritization can be explained by the following process:

Step 1: RAHP hierarchy establishment - The hierarchical structure of general AHP will go through inversion, and the RAHP hierarchy at this point is the reverse process of general AHP (See Formula (3)). Performing this hierarchy is based on Bayes' theorem, as illustrated in the following structure. A is the General AHP's prioritization, and c1, c2, and c3 are the perspective criteria as a posterior probability.

Step 2: The computation of general AHP weight (Δ_s) - In order to compute the RAHP preference ranking of the Equation 1, weight in prioritization by means of general AHP is defined as Δ_s and preference in prioritization by RAHP is defined as Δ_b. Then, each sub-criteria (A1.1.1, A1.2.1 ……A3.10.3)'s five maximum preference values of Δ_s are compared and allocated. The study obtains an A(R) by applying the weight (Δ_s) of general AHP:

$$A(R) = \text{Rank (Weight of alternatives)} \quad (4)$$

Step 3: Computation of RAHP prioritization - In order to compute RAHP Prioritization by choosing alternatives via Δ_s application, pair-wise comparisons are made according to each sub-criteria, and preference weights are computed following the method identical to the general AHP process on the basis of three perspectives (c1, c2, c3). Under the c1, c2, c3 preference ordering for sub-criteria, we will be able to obtain a, b, c in sub-criteria respectably:

$$a_{(i,j)} = \text{Rank}(c1_{(i,j),k})$$
$$b_{(i,j)} = \text{Rank}(c2_{(i,j),k})$$
$$c_{(i,j)} = \text{Rank}(c3_{(i,j),k}),\quad {}_{i,j,k} \text{ is integer} \quad (5)$$

$$P = a + b + c \text{ (P is } a_{(i,j)}, b_{(i,j)}, c_{(i,j)}\text{), respectively} \quad (6)$$

$$Q = \text{Rank}(\min P) \quad (7)$$

For example, general AHP (Δ_s) criteria priority ($_{i,j}$) ranking is compare to rank ($c1_{(i,j),k}$) on the basis of c1 from Table 1.

Step 4: Final prioritization of RAHP - Aforementioned combination formula (3) through (7) is repeatedly computed, and the resulting final ranking value (Q) is reallocated on the basis of Δ_b's prioritization ranking.

PROPOSED MODEL

Overall process for technology prioritization and empirical judgment

This proposed model describes construction of prioritization and empirical judgment process for emerging IT technology selection. The overall process consists of two parts. Part 1 is a priority factors in the selection process for emerging IT technology as used in general AHP, and the other is reverse AHP (RAHP) experiment for current prioritization by general AHP. Part 2 is empirical judgment process for priorities by AHP and RAHP. Empirical judgment aims to confirm the reliability of the judgment method by comparatively evaluating and

Table 1. An example of application of system and devices (${}_i$) by general AHP (Δ_s).

Criteria (${}_j$)	Sub-criteria (${}_k$)	Alternative	Weight
	Display device	Technical	0.0156
		Strategic	0.0055
		Economical	0.0456
		Sub-tot	0.0668
	Audio device	Technical	0.0053
		Strategic	0.0027
		Economical	0.0114
		Sub-tot	0.0193
Digital electronic appliances	Home server	Technical	0.0125
		Strategic	0.0082
		Economical	0.0393
		Sub-tot	0.0599
	Storage device	Technical	0.0215
		Strategic	0.0159
		Economical	0.0346
		Sub-tot	0.0720
	Entertainment	Technical	0.0104
		Strategic	0.0058
		Economical	0.0237
		Sub-tot	0.0399
		Total	0.2579

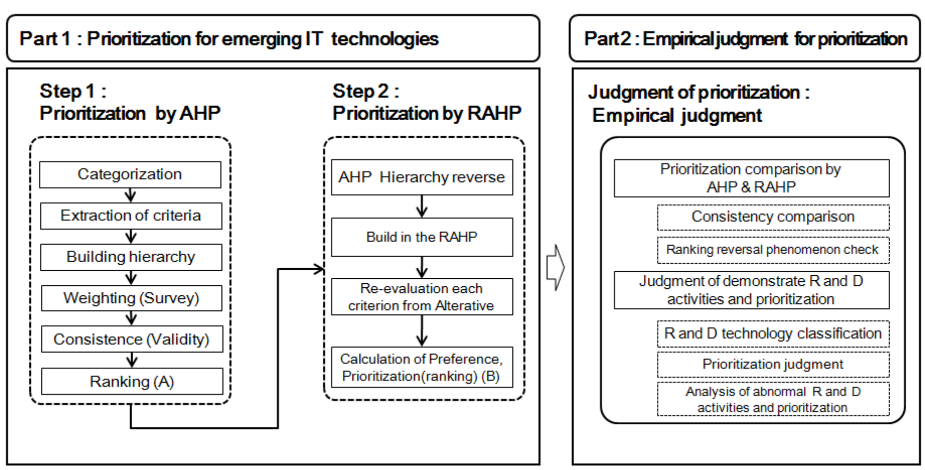

Figure 3. Overall process of prioritization and empirical judgment for emerging IT technologies.

analyzing the promising technology prioritization (rank) of AHP and results of R&D activities that actually carry out the emerging IT technologies selection activity by means of AHP by institutions involved in discovering and examination of promising technology. However, note that electronic device technology has sub-technologies and '2003 Prioritization and Selection' project was executed for selection of the technologies prioritization in South Korea. The overall proposed process is illustrated in Figure 3.

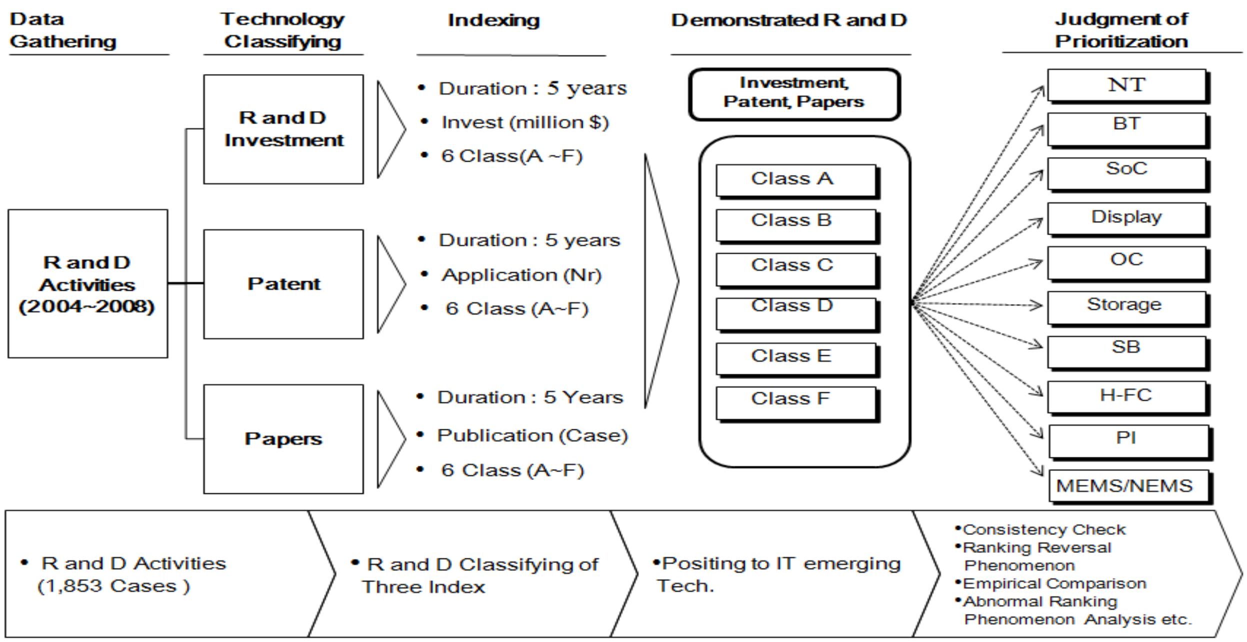

Figure 4. Overall process for empirical judgment between demonstrated R&D activities and prioritization.

EMPIRICAL STUDY

Part 1: Prioritization for emerging IT technologies by AHP and RAHP

For the application of the AHP, the italicized words such as major technologies, categories, criteria, and sub-criteria are reserved for indicating a specific set of technologies (Figure 1, Appendix). For our empirical studies, we have considered the 13 major technologies (A1, A2 and A3.1 to A3.11) that could be grouped into the three categories A1 to A3 (Table 1). It should be mentioned here that the category A3 is introduced only for a technically simple hierarchy representation of AHP, not for actual classification of technologies. Following the suggestions made by the experts, we have employed the hierarchical structure. Indeed, The AHP is the 5-level hierarchical structure and, at its bottom, the 242 specific alternatives are classified as belonging to one of the 73 sub-criteria at the level immediately above. A complete hierarchical structure of AHP with detailed enumeration of technologies is given in Figure 4. The study used a five-level hierarchy for c1 to c3 at the level immediately below the 73 sub-criteria instead. This is done mainly because recovering the causes for the 242 alternatives is likely to suffer from efficiency loss by performing too many pair comparisons for those surveyed. AHP survey was conducted for the proposed AHP model at each level. AHP survey targeted middle managers who had worked for more than 5 years in the related industry, university research laboratories, and national agencies. Research data used in this study were collected from August to October 2003. A total of 107 experts participated in our survey. In order to conduct the analysis accurately, all abnormal responses were excluded. According to prior studies on AHP, CR between 0.5 and 1.5 is considered an ideally consistent response. However, in our study, the responses with CR exceeding 0.2 were eliminated due to the deficiency of responses. Thus, the study developed a computer-based survey environment that captured expert's opinions on the internet and every priorities and preferences are calculated by Expert 2000 Software.

Table 2 shows the electronic device technologies resulted by means of CR consistency. Selected technologies are arranged in order of ranking from left to right. From Table 2, we may conclude that government and electronics companies in Korea should focus on investment.

Prioritization by RAHP

In other to double-check prioritization by general AHP method, execution of prioritizing by using RAHP was attempted. The pair-wise comparison AHP method originated from psychological research. In advance, new criteria are needed for application of RAHP method on prioritization of emerging technologies selected by AHP (Table 3). That is, there is a need for judgment standard on the sub-criteria in the general AHP priorities.To create the categories, alternatives were selected on the basis of the 3 perspectives: technical (c1), strategic (c2) and economical (c3). The 3 perspectives were classified by

Table 2. Results of CR.

Good CR consistency				Bad CR consistency	
Under 0.1		**0.1 ~ 0.2**		**Over 0.2**	
Priority by AHP					
A1 System and device	0.097	A2 Network	0.129	A9 Storage	0.746
A4 Bio tech	0.098	A3 Nano Tech	0.131		
A7 Display	0.061	A6 SoC	0.142		
A8 Optical components	0.089	A10 Secondary battery	0.119		
A11 RF Communication	0.094				
A12 Precision instrument	0.086				
A13 MEMS/NEMS	0.075				
Preference by AHP					
A1 System and device	0.090	A2 Network	0.127	A9 Storage	0.497
A4 Bio tech	0.086	A3 Nano tech	0.091		
A7 Display	0.091	A6 SoC	0.135		
A8 Optical components	0.092	A10 Secondary battery	0.120		
A11 RF communication	0.089				
A12 Precision instrument	0.187				
A13 MEMS/NEMS	0.044				

Table 3. Selected electronic device technologies.

R&D areas		1st	2nd	3rd	4th	5th
A1	System and device	4G handsets	D-TV	IMT-2000	Telematics	Game
A2	Network	xDSL	Bluetooth	WDM	UWB	Ethernet
A3	NT(Nano Tech)	Transistor	Nano-CMOS	Luminous element	Photodetector	SET
A4	BT(Bio Tech)	Bio-sensor	Microfluidics Chip	Bio Probe	Cell Detector	Bio-chip
A6	SoC	DMB chipset	Sender/ Receiver chipset	PVR chipset	MODEM	3D Terminal chipset
A7	Display	LCD	E-Paper	EL	Projection	PDP
A8	Optical components	Optical source	Optical transmitter	Opto. electricity integrated circuit	Wire and Wireless Integration Comp.	Optical amplifier
A9	Storage	HDD	SPM storage	HDDS	Flash	MRAM
A10	Secondary battery	Super capacitor	Ion	Ion Polymer	Polymer	Ni-MH
A11	RF Communication	Integrated RF module	FEM	RF-ID	PAM	Amplifier
A12	Precision Instrument	Micro manipulator	Smart Arm	MEMS Actuator	Nano class stage	Image detection module
A13	MEMS/NEMS	Optical switch	VOD	Nano Scanner	Microphone Chip	MEMS Switch

Stewart (1995) where main factors were selected by decision makers since the initiation of national R&D projects. And the 3 criteria are also a process requiring firm commitment of the governments, companies and R&D sectors, and involve systematic procedures aimed at shaping common visions of the country and regional futures, based on changing needs of the society resulting (in part) from technological advances (UNIDO, 2001). Therefore, based on the 3 perspectives, a total of 19 sub-criteria were extracted from preceding research. Table 4 describes the 19 technology and references. RAHP was conducted to analyze technical devices of recent prioritizing technologies.

Figure 2 illustrates a general hierarchy followed from the decomposition of emerging technologies at different levels from general to details. In this case, the only single criterion (that is, s1, "choosing best emerging technologies") may implicitly serve at each level for pair-wise comparison of technologies and, hence, the entire hierarchy. Of course, s1 might be decomposed into more specific scales such as technical (c1), strategic (c2), and economical (c3) perspectives, but such decomposition tends to cause technical difficulties. In the following, we discuss the related practical issues including the details of the three perspectives.

Through A prioritization by the general AHP, we selected the proper emerging technologies via the general AHP (Δ_s) and then, using the RAHP (Δ_b), we assessed the selected emerging technologies on c1~c3 scales - technical, strategic and economical perspectives (Kim et al., 2010). Θ and X corresponded to the c1~c3 scales and the set of technologies in the regular hierarchy shown in Figure 1, respectively.

Notice also that the RAHP in Figure 2 puts c1~c3 scales at its bottom and, hence, it is a kind of inversion of the regular hierarchy based on direct decomposition of s1 into c1~c3 scales in the sense that it turns the upside of such regular hierarchy down. Since A3 is introduced for technically simple hierarchical representation of Δ_s and Δ_b , CR values are calculated for the major technologies except A3.3. As illustrated in Table 2, A3.7 (storage) exhibits a high value of CR and all the major technologies except for A3.7 and A3.3 bear adequate CR values for the RAHP surveys and, hence, are reliable. Since Δ_b yields more consistent CR's than Δ_s in the sense that CR values from Δ_b are less than those from Δ_s , the RAHP appears to improve efficiency of Δ_s by employing the Bayesian concept of AHP. Figure 2 provides some of the calculated priorities (or weights) from the application of Δ_s. From the application of Δ_s , we easily obtained top 5 specific alternatives within each of 13 major technologies (that is, A1, A2, A3.1 to A.3.11) as shown in Table 5.

Results from Δ_b application are given in Table 6 whichprovides each sub-criterion within each of the 13 major technologies with their priority ordering, obtained by applying. Now using the calculated priorities of the sub-criteria obtained by Δ_b , we rearrange the top 5 specific alternatives within each of 13 major technologies given in Table 7. More specifically, we calculated them according to Equations 3 to 7.

Part 2: Empirical judgment for prioritization

Prioritization comparison between AHP and RAHP

First, assess the extent of consistency of results of priority ranking and results of R&D activities through comparison of consistency between the results of prioritization of emerging IT technology by AHP and RAHP. That is, judge whether substantial R&D investment has been made into technologies that had been selected as the future emerging technology. We stated that indices such as R&D investment, patent and papers impart substantial influence on the R&D activities. Table 7 shows a combination of the prioritization result according to the AHP and RAHP experiments. Bold letters are discordance ranking between AHP and RAHP.

Consistency check of prioritization ranking between AHP and RAHP

The extent of consistency check is examined in order to achieve more meticulous priority judgment between the general AHP prioritization and RAHP prioritization. Compute the consistency in order to determine the consistency between the AHP prioritization ranking and RAHP prioritization ranking. If the general AHP and RAHP ranking has same priority for technology A, it is expressed as (sum of number of entities with consistency (1)/sum of number of entities of technology (A) * 100. Consistency checks, which are the results of the comparison of priorities, 26 technologies out of total of 60 technologies displayed consistency ratio of 100% while the remaining 34 technologies showed inconsistency of priority. It is presumed that this low consistency ratio is generated by various causes. That is, increase in the uncertainty generated due to the passage of time from the time of discovery of the emerging technology may be the main cause. The factors for such increase in uncertainty may include changes in the market conditions, adjustment of national R&D investment policies, immaturity of technology, and error in the judgment of the responders.

Ranking reversal phenomenon check

For the choice and selection of Emerging IT technologies, each of the prioritization judgment and ranking reversal

Table 4. Description and reference of 19 technology based on 3 perspective.

Perspective	variable	Description	Reference
Economical	Market	ROI, ROS, Market demand level, Market size, Barriers to Entry, etc.	Dearden (1969),
	Growth	Increase of asset/equity capital/asset/ordinary income. Increase in added value/sales/labor cost per employee etc.	Ohlson (1995)
	Stability	Current/debt/fixed debt/equity capital ratio etc. Over 200% standard current ratio shows high stability	Thomas (2009)
	Profit	Sales-operating profit ratio, Sales-net profit ratio, Total asset-net profit ratio, equity capital-net profit ratio, Sales increasing ratio etc.	Woo and Willard(1983), Ohlson (1995)
	Productivity	Added value/Sales per employee, Added value ratio, Efficiency in equipment investment, Efficiency in instrument investment etc.	Loggerenberg (1982), Banker et al. (1989)
	R and Expenditure	R&D organization panels' average R&D expenditure from '03 to'08 (100mil., 300mil., 500mil., Billion, over Billion)	Likert scale (1932), R&D organization panels
Technical	Tech. Level	Developing core technology, design/development of new product, improvement of existing products, Relative technology level to advanced countries	Park et al. (2006) R&D organization panels
	Possibility for Success	High/low degree of possibility for success(very low, low, average, high, very high)	Likert scale (1932), organization panels
	Intellectual property	Based on R&D organization panels' average IP applications from '03 to'08 (0.1 ~ over 1.3)	Likert scale (1932), R&D organization panels
	Possibility for commercialization	Stage classification by Likert scale (very low, low, average, high, very high)	Likert scale (1932)
	R&D lead Time	R and D Organization panels' average research period	Jeanne et al. (2000)
	Researchers	R&D Organization panels' researchers for each research area by Likert scale (3 ~ over 21)	Likert scale (1932), R&D Organization panels
	Originality	Likert scale as a technology level by progressivity and newness (very weak, weak, average, strong, very strong)	Likert scale (1932)
	R&D resources	R&D Organization panels' average R&D expenditure for each research by Likert scale (100 mil. ~ over 800 mil.)	Likert scale (1932), R&D organization panels
Strategic	Public interest	Coincidence with public interest by Qualitative decision	Likert scale (1932)
	Assist in industrial development	Assisting degrees in industrial development by Qualitative decision	Likert scale (1932)
	Strengthening national base technologies	Assisting degrees in strengthening national base technologies by Qualitative decision	Likert scale (1932)
	Coincidence with National R&D	Coincidence with national technology strategy like NTRM	Likert scale (1932)
	Diffusion on industry	R&D results' possibility of diffusion to other industry	Likert scale(1932)

Table 5. Selected alternatives via Δs application.

	R&D	1st	2nd	3rd	4th	5th
A1	System and device	4G (3)	D-TV (8)	IMT-2000(3)	Telematics (5)	Game (11)
A2	Network	xDSL (5)	Bluetooth (4)	WDM (4)	UWB (4)	Ethernet (4)
A3	A3.1 NT (Nano tech.)	Transistor (3)	Nano-CMOS (3)	Luminous element (8)	Photo detector(8)	SET (3)
	A3.2 BT (bio tech.)	Bio-sensor (4)	Microfluidics Chip (5)	Bio probe (4)	Cell detector (4)	Bio-chip(5)
	A3.4 SoC	DMB Chipset (3)	Transmitter/receiver chipset (13)	PVR chipset (3)	MODEM (8)	3D device chipset (3)
	A3.5 Display	LCD (4)	E-Paper (5)	EL (4)	Projection (13)	PDP (4)
	A3.6 Optical components	Optical source (5)	Optical transmitter (5)	Opto electricity accumulation circuit (4)	Wire/wireless integrated comp. (4)	Optical amplifier (5)
	A3.7 Storage	HDD (8)	SPM storage (8)	HDDS (9)	Flash (8)	MRAM (8)
	A3.8 Secondary battery	Super capacity capacitor battery (6)	Ion (3)	Ion polymer (3)	Polymer (3)	Ni-MH (10)
	A3.9 High frequency communication	RF integrated module (3)	FEM (3)	RF-ID (3)	PAM (6)	Amplifier AMP (6)
	A3.10 Precision instrument	Micro manipulator (6)	Smart arm (9)	Super-precision controller (6)	Nano class stage (6)	Image detection module (9)
	A3.11 MEMS/NEMS	Optical switch (4)	VOD (4)	Nano scanner (9)	Microphone chip (5)	MEMS switch (5)

Table 6. Final result of RAHP application to choosing best emerging technologies.

R&D			1st	2nd	3rd	4th	5th
A1	System and device		4G	IMT-2000	Telematics	D-TV	Game
A2	Network		Bluetooth	WDM	UWB	Ethernet	xDSL
A3	A3.1	NT (Nano Tech.)	Transistor	Nano-CMOS	SET	Luminous Element	Photodetector
	A3.2	BT (Bio Tech.)	Bio-sensor	Bio Probe	Cell detector	Microfluidics chip	Bio-chip
	A3.4	SoC	DMB Chipset	PVR chipset	3D device chipset	MODEM	Transmitter /Receiver chipset
	A3.5	Display	LCD	EL	PDP	E-Paper	Projection
	A3.6	Optical components	Opto electricity integrated circuit	Wire/ wireless integration comp.	Optical source	Optical transmitter	Optical amplifier
	A3.7	Storage	HDD	SPM Storage	Flash	MRAM	HDDS
	A3.8	Secondary battery	Ion	Ion polymer	Polymer	Super capacity /capacitor battery	Ni-MH
	A3.9	High- frequency communication	RF integrated module	FEM	RF-ID	PAM	Amplifier AMP
	A3.10	Precision instrument	Micro manipulator	Super-precision controller	Nano Class Stage	Smart arm	Image detection module
	A3.11	MEMS/NEMS	Optical switch	VOD	Microphone CHIP	MEMS switch	Nano scanner

phenomenon will be examined through method described. Final prioritization of emerging IT technologies in accordance with reverse AHP as illustrated in Table 7 is the method of minimizing ranking (prioritization) reversal phenomenon of the RAHP results. Then, comparison on the

Table 7. The comparison of prioritization (rank) by AHP and RAHP.

Category			1st	2nd	3rd	4th	5th
A1	System and device		4G (1)	IMT-2000 3)	Telematics(4)	D-TV (2)	Game (5)
A2	Network		Bluetooth (2)	WDM (3)	UWB (3)	Ethernet (5)	x DSL (1)
	A3.1	NT (Nano Tech.)	Transistor (1)	Nano-CMOS(2)	SET (5)	Luminous Element(3)	Photodetector (4)
A3	A3.2	BT (Bio Tech.)	Bio-sensor (1)	Bio Probe (3)	Cell Detector (4)	Microfluidics Chip(2)	Bio-chip (5)
	A3.4	SoC	DMB chipset (1)	PVR chipset (3)	3D device chipset (4)	MODEM (4)	Transmitter / receiver chipset (2)
	A3.5	Display	LCD (1)	EL (3)	PDP (5)	E-Paper (2)	Projection(4)
	A3.6	Optical components	Opto Electricity Integrated Circuit (3)	Wire/ Wireless Integration Comp. (4)	Optical Source (1)	Optical Transmitter (2)	Optical amplifier (5)
	A3.7	Storage	HDD (1)	SPM Storage (2)	HDDS(3)	Flash (4)	MRAM (5)
	A3.8	Secondary battery	Ion (2)	Ion Polymer (3)	Polymer (4)	Super capacity/capacitor battery(1)	Ni-MH (5)
	A3.9	High- frequency communication	RF integrated module (1)	FEM (2)	RF-ID (3)	PAM (4)	Amplifier AMP (5)
	A3.10	Precision Instrument	Micro Manipulator (1)	Nano class stage (4)	Smart arm (2)	Super- precision controller (3)	Image detection module (5)
	A3.11	MEMS/ NEMS	Optical Switch (1)	VOD (2)	Microphone Chip (4)	MEMS Switch (5)	Nano Scanner (3)

* ( ) means prioritization ranking result from general AHP experiment (Δs).

results of regular AHP ranking is carried out. Future emerging technologies selection is not easy to predict the future due to the fact that current prioritization (ranking) factors could be changed as the time goes on. Accordingly, the study needs certain level of uncertainty tolerance ratios in order to carry out verification (Ilbery and Sunter, 2005).

Empirical comparison of demonstrated R&D activities and (R) AHP prioritization

Emerging IT technology selection is a very important indicator for productivity and competitiveness of a country, and has thus become a central topic of economic analysis in most industrialized countries. For analysis of science and technology activities in quantitative terms, analysts employ various indicators such as R&D budgets, R&D personnel, production and foreign trade of technology-intensive goods (Schmoch, 1999; Grupp, 1994, 1998). In particular, number of country-led R&D cases, R&D funds, R&D manpower, patent and papers are used frequently as important judgment indices at the time of emerging technology selecting. In this study, empirical judgment study on R&D activities and emerging technology priorities is execute on the basis on 3 of judgment criteria: (a) R&D investment (b) Patent and (c) Papers. Here, empirical comparison for judgment is used in order to evaluate the results of proper selection between empirical R&D activities and prioritization. Results of R&D activities and prioritization over a period of 5 years for the total of 10 technologies are empirically compared. In advance, empirical comparison and judgment on the results of two kind of AHP prioritization are carried out in accordance with several principles. First is the setting of duration of subjects for empirical comparison. Duration of extracting survey by general AHP methodology was limited to 5 years from 2004 to 2008 with “prioritization of emerging IT technology 2003” as the standard.

Figure 4 illustrates the overall process for empirical judgment between demonstrated R&D activities. This study was able to determine that indices such as R&D Investment, patent and papers impart substantial influence on the R&D activities. Therefore, it is obvious that greater R&D activities occur for the emerging technology with higher priority. Then, ranking reversal phenol-menon for assessment of consistency between AHP and RAHP prioritization ranking is subjected to comparative analysis. This is to judge the extent of occurrence of allowable error in the future uncertainty by examining the changes in the ranking orders of each of the selected technologies among the diverse range of emerging IT technologies in accordance with prioritizations of general AHP and RAHP.

Technology classification of demonstrated R&D activities

R&D activity indices are divided into total of three evaluation indices (R&D investment, Patent and Papers). These are generally used as research activity indices of public research institutions. Recently, technology commercialization performance has been included in addition to the 3 mentioned criteria. For more accurate empirical comparison, each of the R&D activity indices were consolidated and categorized as follows. Criteria for application of activity indices of research institutes subjected to survey were consolidated through the following phases. R&D activity indices are divided into a total of 3 evaluation indices (R&D investment, Patent and Papers). These are generally used as research activity indices on public research institutions.

Empirical comparison of prioritization and demonstrated R&D activities

At this stage, only the appropriate data from the basic data obtained through database on the research activities results over the last 5 years were selected by limiting them to 10 technologies that have been designated as emerging technology among the R&D technologies of the institutions subjected to survey, and were directly in consistency with the corresponding technologies. Categorization and comparison of data was carried out into 5 classes with rating of A as the most outstanding and rating of F as the lowest. ‘R&D investment’ refers to the status of executed R&D activities of surveyed institution for the 10 technologies. ‘R&D investment’ is also expressed in terms of ‘Class A to F’ because of restricted documents in institution. The classes (million dollar) signifies that class A is above 5, class B is 4 and 3, class C is 3 and 2, class D is 2 and 1, class E is 1 and 0.5, and class F is below 0.5. And also, the ‘patent and papers’ are simply expressed in terms of Class A ranking to E ranking for the technology groups.

First, each of the R&D investment (R&DI) on the results of general AHP and RAHP prioritization were compared. Judgment on whether R&D investment on the prioritization has occurred was the comparison condition. It should be noted here that just because the size of R&D investment (R&DI) is large, it does not necessarily coincide with emerging technology priority because even if a technology has been selected for inclusion in the high priority ranking, the investment priority may change at the time of final R&D investment due to numerous variables. Therefore, since the prioritization ranks and R&DI ranking may not be the same, only whether investment on the emerging technology has been made was used as the judgment criteria in this study. The following is the application of consistency (percentage of generation of investment) between the results of experimental R&D investment (R&DI) comparison resulted from AHP and RAHP. Table 8 is arranged by experimental R&D investment (R&DI) based comparison resulted from AHP and RAHP.

Table 9 is experimental consistency comparison, which resulted from prioritization (AHP and RAHP) and R&D investment (R&DI). RAHP prioritization result is more precise by about 2%. However, deviation of 2% in the judgment between the 2 methods signifies that the two methodologies have high level of consistency from the perspectives of the usefulness of AHP methodology, and that the RAHP methodology has slightly higher reliability. Moreover, due to the fact that investments were made only for the BT and MEMS/NEMS technology that were ranked the 1st, the overall R&D investment (R&DI) consistent measure was a little low at 62 and 64%, respectively. However, from the viewpoint of R&D fields, there is no regulation that stipulates that R&D investment activities need to be made evenly for all the 5 emerging technologies. Therefore, with regards to the “BT and MEMS/NEMS” technologies, since the judgment criteria do not stipulate that ‘investment must be made for all 5 selected technologies’, it would be fine to select only the most preferred technology in accordance with the R&D investment circumstances, from the position of the policy maker for R&D investment. Accordingly, from the selection viewpoint of the decision maker, the consistency ratio is 78 and 80% for AHP and RAHP, respectively. Therefore, it can be deemed that application of AHP methodology for selection of emerging technology is outstanding.

Abnormal phenomenon analysis of prioritization and demonstrated R&D activities

Abnormal reasons occurred in 12 items out of the total 50 consistencies or inconsistency technologies in which abnormal R&D investment (R&DI) activities were generated. Most of the inconsistent reason is as follows: immaturity of the market, enterprise led technology, upgrade to R&D technology, increase in interest items, etc.

CONCLUSION

This study presented reverse AHP methodology as real time judgment methodology since there is no appropriate decision making tool for selection of emerging technology by AHP because of the absence of need for proper decision making method for IT technologies without forecasting methodology.

As a result of the experiment in which reverse AHP method was added, priority of promising technology through general AHP methodology and the results of reverse AHP comparison and prioritizing displayed approximately 2% consistency deviation. It is deemed that the extent of consistency is high. But the selection activities for future emerging technologies themselves contain uncertainties due to emergence of diverse range

Table 8. Demonstrated R&D investment (R&DI) compared to result from AHP and RAHP.

Technology	Contents	Current status of actual R&D spending funds as demonstrated data ('04 ~ '08)					Consistency (%)
	Ranking	1st	2nd	3rd	4th	5th	
NT	R&DI	Transistor	Luminous element	Nano-CMOS	SET	-	
	AHP (a)	Transistor	Nano-CMOS	Luminous element	Photo detector	SET	60
	RAHP (b)	Transistor	Nano-CMOS	SET	Luminous element	Photo Detector	80
BT	R&DI	Bio-sensor	-	-	-	-	
	AHP	Bio-sensor	Microfluidics	Bio probe	Cell Detector	Bio-chip	20
	RAHP	Bio-sensor	Bio Probe	Cell detector	Microfluidics	Bio-chip	20
SoC	R&DI	MODEM	Transmitter/Rec. chipset	3D device chipset	DMB chipset	PVR chipset	
	AHP	DMB chipset	Transmitter/Rec. chipset	PVR chipset	MODEM	3D device chipset	100
	RAHP	DMB chipset	PVR Chipset	3D device chipset	MODEM	Transmitter/Rec. chipset	100
Display	R&DI	EL	LCD	E-paper	PDP	Projection	
	AHP	LCD	E-paper	EL	Projection	PDP	100
	RAHP	LCD	EL	PDP	E-paper	Projection	100
OC	R&DI	Optical source	Opto electricity IC	-	-	-	
	AHP	Optical source	Optical transmitter	Opto electricity IC	Wire/wireless Comp.	Optical amplifier	40
	RAHP	Opto electricity IC	Wire/wireless. comp.	Optical Source	Optical transmitter	Optical amplifier	40
Storage	R&DI	SPM storage	HDD	-	-	-	
	AHP	HDD	SPM storage	HDDS	Flash	MRAM	40
	RAHP	HDD	SPM storage	HDDS	Flash	MRAM	40
SB	R&DI	Ion polymer	Super Capa city CB				
	AHP	Super capacity CB	Ion	Ion polymer	Polymer	Ni-MH	40
	RAHP	Ion	Ion Polymer	Polymer	Super capacity CB	Ni-MH	40
H-FC	R&DI	RF integrated module	Amplifier AMP	PAM	FEM	RF-ID	
	AHP	RF integrated module	FEM	RF-ID	PAM	Amplifier AMP	100
	RAHP	RF integrated module	FEM	RF-ID	PAM	Amplifier AMP	100
PI	R&DI	Super precision Con.	Image detection module	Smart arm	Micro manipulator	Nano class stage	
	AHP	Micro manipulator	Smart arm	Super precision con.	Nano class stage	Image detection module	100
	RAHP	Micro manipulator	Nano class stage.	Smart arm	Super precision con	Image detection module	100
MEMS/ NEMS	R&DI	Optical switch	-	-	-	-	
	AHP	Optical switch	VOD	Nano scanner	Microphone chip	MEMS switch	20
	RAHP	Optical switch	VOD	Microphone chip	MEMS Switch	Nano scanner	20

*(a) is priority ranking of regular AHP experimented, and (b) is the preference ranking of RAHP experimented.

Table 9. Consistency comparison of demonstrated R&D investment (R&DI) and prioritization of AHP and RAHP.

Methodology	R&DI / Technologies occurrence BT, NT include	Consistency ratio (%)	Remark
AHP	31/50	62	
	39/50	78	
RAHP	32/50	64	-
	40/50	80	

of variables that cannot be anticipated with passage of time. Ilbery and Sunter (2005) asserted, in 'The cone of Uncertainty', that selection of emerging technologies at present brings about increase in uncertainty as time passes, and this induces diversification of variables, that is, occurrence of error. Therefore, allowable error (rank reversal ±1) should be applied to the results of occurrence of priority reversal of the results in this Study. Lastly, empirical comparison study of AHP and RAHP was carried out on the results of R&D activities carried out by the institutions subjected to survey in order to judge the reliability of AHP prioritization results. Moreover, empirical comparison judgment was carried out for the results of discovery by AHP and RAHP as promising technology. From the results of analysis, it was possible to confirm that R&D investment activities were further reinforced for higher ranked technologies, and confirmed that R&D activities definitively occurred with focus on the items for which consistency between AHP and RAHP occurred. Finally, empirical judgment between empirical R&D activities and usefulness of AHP methodologies that considers allowable consistency ratio was 78.4%, which enables one to deem AHP methodology as quite a good judgment methodology.

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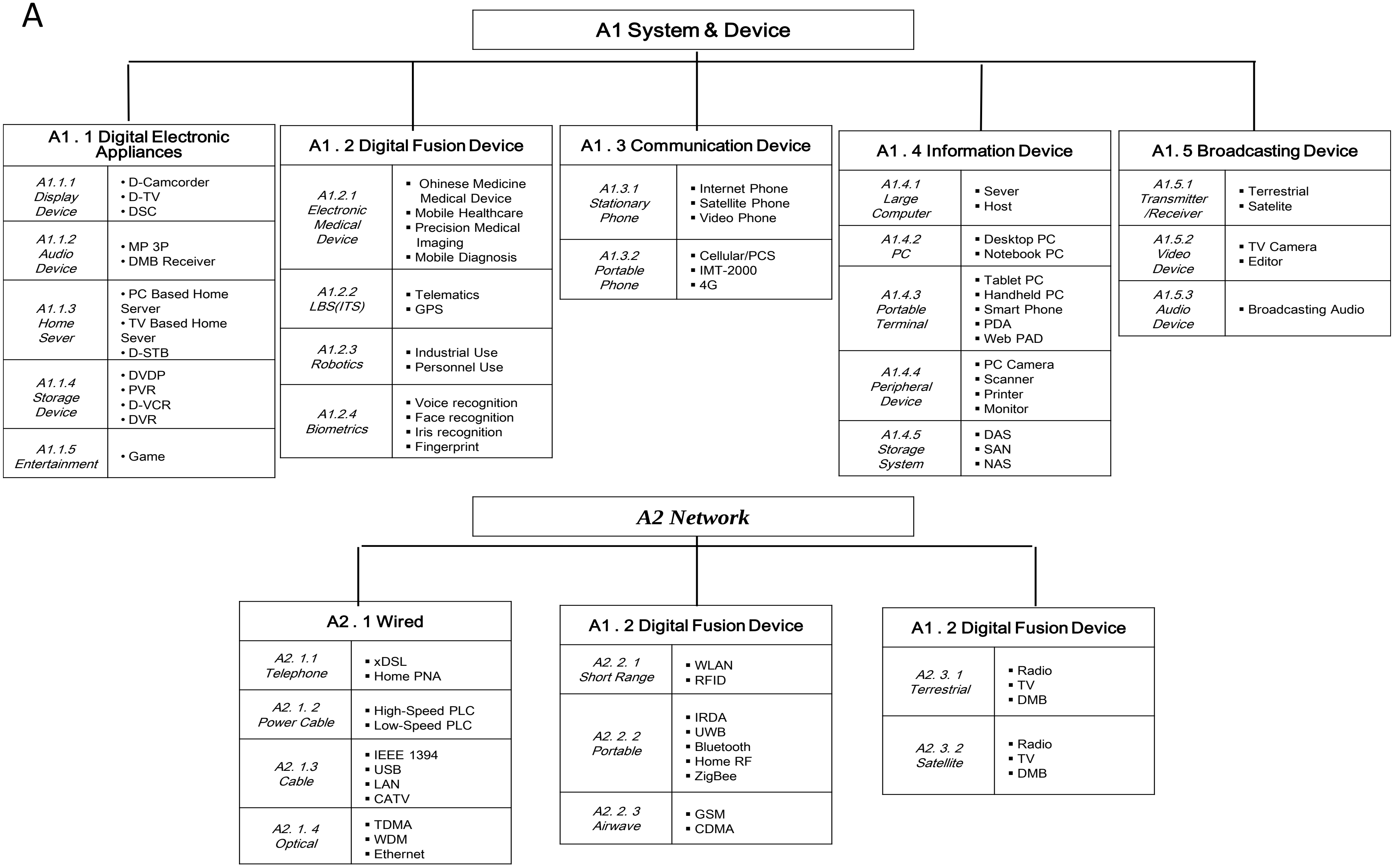
APPENDIX

A


A1 System & Device
A1 . 1 Digital Electronic Appliances
A1.1.1 Display Device
• D-Camcorder
• D-TV
• DSC
A1.1.2 Audio Device
• MP 3P
• DMB Receiver
A1.1.3 Home Sever
• PC Based Home Server
• TV Based Home Sever
• D-STB
A1.1.4 Storage Device
• DVDP
• PVR
• D-VCR
• DVR
A1.1.5 Entertainment
• Game
A1 . 2 Digital Fusion Device
A1.2.1 Electronic Medical Device
▪ Ohinese Medicine Medical Device
▪ Mobile Healthcare
▪ Precision Medical Imaging
▪ Mobile Diagnosis
A1.2.2 LBS(ITS)
▪ Telematics
▪ GPS
A1.2.3 Robotics
▪ Industrial Use
▪ Personnel Use
A1.2.4 Biometrics
▪ Voice recognition
▪ Face recognition
▪ Iris recognition
▪ Fingerprint
A1 . 3 Communication Device
A1.3.1 Stationary Phone
▪ Internet Phone
▪ Satellite Phone
▪ Video Phone
A1.3.2 Portable Phone
▪ Cellular/PCS
▪ IMT-2000
▪ 4G
A1 . 4 Information Device
A1.4.1 Large Computer
▪ Sever
▪ Host
A1.4.2 PC
▪ Desktop PC
▪ Notebook PC
A1.4.3 Portable Terminal
▪ Tablet PC
▪ Handheld PC
▪ Smart Phone
▪ PDA
▪ Web PAD
A1.4.4 Peripheral Device
▪ PC Camera
▪ Scanner
▪ Printer
▪ Monitor
A1.4.5 Storage System
▪ DAS
▪ SAN
▪ NAS
A1. 5 Broadcasting Device
A1.5.1 Transmitter /Receiver
▪ Terrestrial
▪ Satelite
A1.5.2 Video Device
▪ TV Camera
▪ Editor
A1.5.3 Audio Device
▪ Broadcasting Audio
A2 Network
A2 . 1 Wired
A2. 1.1 Telephone
▪ xDSL
▪ Home PNA
A2. 1. 2 Power Cable
▪ High-Speed PLC
▪ Low-Speed PLC
A2. 1.3 Cable
▪ IEEE 1394
▪ USB
▪ LAN
▪ CATV
A2. 1. 4 Optical
▪ TDMA
▪ WDM
▪ Ethernet
A1 . 2 Digital Fusion Device
A2. 2. 1 Short Range
▪ WLAN
▪ RFID
A2. 2. 2 Portable
▪ IRDA
▪ UWB
▪ Bluetooth
▪ Home RF
▪ ZigBee
A2. 2. 3 Airwave
▪ GSM
▪ CDMA
A1 . 2 Digital Fusion Device
A2. 3. 1 Terrestrial
▪ Radio
▪ TV
▪ DMB
A2. 3. 2 Satellite
▪ Radio
▪ TV
▪ DMB

B

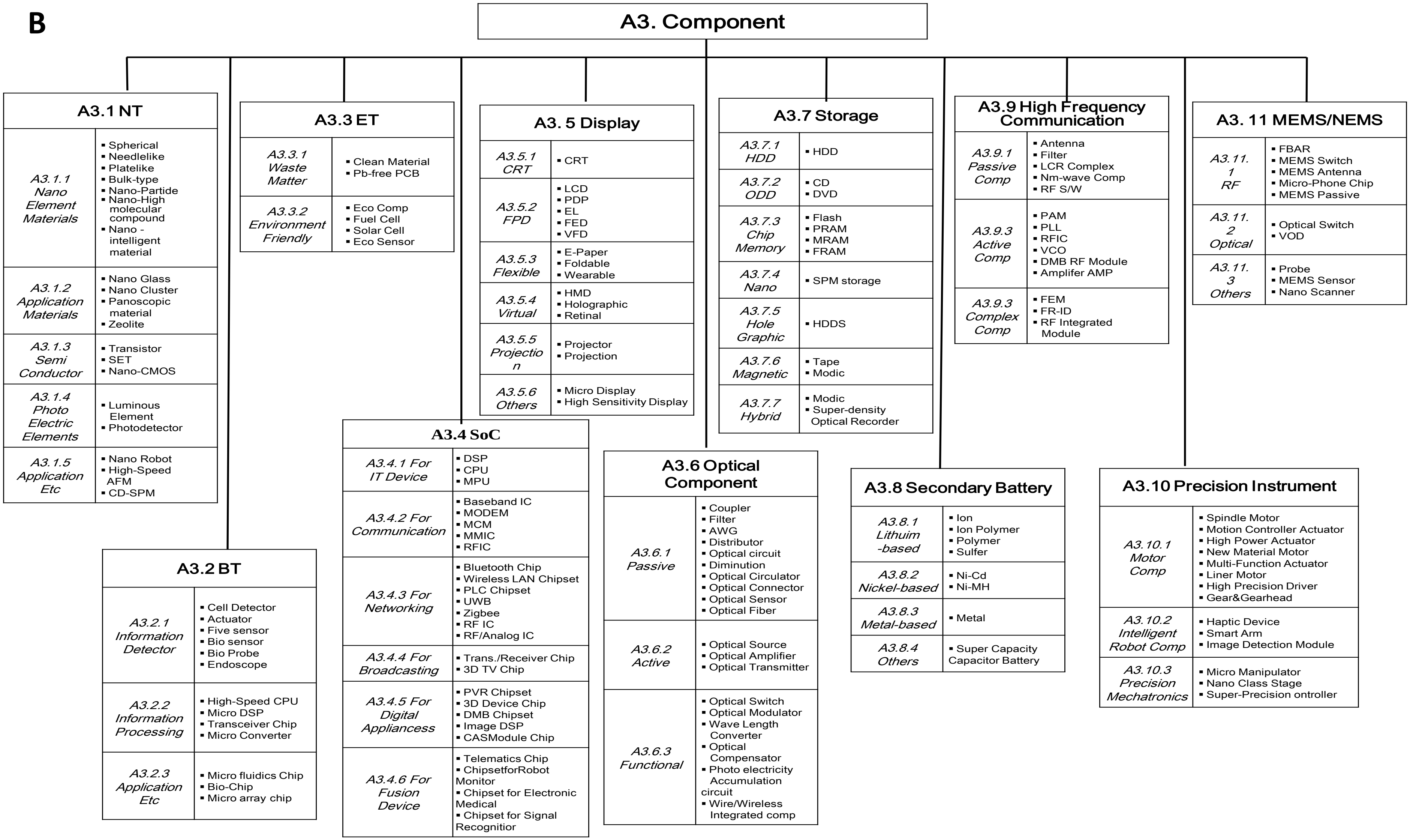


Figure 1. The expanded hierarchy of the proposed AHP model; a) system and device, network; b) components.