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Future technology analysis for biosecurity and emerging infectious diseases in Asia-Pacific

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This paper presents a future-oriented technology analysis (FTA) project on the control and management of emerging infectious diseases (EID) in the Asia-Pacific Economic Cooperation region. It combines several FTA methods. Technologies that are potentially effective in biosecurity and in combating EID were first identified by bibliometric analysis, online survey and scenario planning. Roadmaps of these technologies were then built. Workshops to conduct the foresight process were held in the region. Four scenarios and six technology roadmaps for the region were developed. The results show that many future technologies will converge to become most effective in dealing with biosecurity and EID. This paper deals with cross-disciplinary technologies in the context of a cross-boundary regional setting, which has important methodological implications.

BIOSECURITY INVOLVES THE POLICIES and measures taken to protect from biological harm. It encompasses the prevention and mitigation from diseases in humans and animals, and bioterrorism that impacts the economy, environment, and public health. More technically, dealing with biosecurity can be considered in terms of information generation and collection, information management, information analysis, and the use of such analysis. Each of these covers a number of disciplines and requires the application of different technologies. Furthermore, biosecurity, and security in general, is also typically related to critical infrastructure, particularly in the area of public health. Compromising biosecurity can have a far-reaching impact on many other social infrastructures and many aspects of human activities, population structures, or even the survival of humankind (in the event of a global pandemic).

One major threat to biosecurity is the outbreak of infectious diseases. Infectious diseases account for a quarter of all human mortality but developing countries have a disproportionate share because of poverty, limited access to health care, drug resistance and changing food supplies due to the impact of climate change on land and water supplies.

Emerging infectious diseases

While severe acute respiratory syndrome (SARS) and avian influenza have attracted major attention in recent years, there have been other emerging infectious diseases (EID) which also present threats to humans and animals. More new diseases have emerged in the past 20 years than in the previous 50 years with the majority of these originating in wildlife. Further, old diseases such as dengue and foot-and-mouth have re-emerged to cause costly epidemics. Eight categories of infectious diseases have been identified as potential threats (World Health Organization, 2006). These are:

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See Acknowledgements on page 50.

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Greg Tegart has had a long and varied career. After graduating in Australia he was an academic in the UK and the US for a number of years followed by administration of industrial research and of government science and technology (S&T) in Australia. He retired from the service of the Australian government in 1993 and has held academic posts in Canberra and Melbourne in the S&T policy area since then. A major activity has been his association with the APEC Center for Technology Foresight since its inception in 1998. He has recently completed his term as chairman of its international advisory board.

Chatri Sripaipan started his career teaching electronics at Chulalongkorn University, Thailand. From 1980, his interest diversified into industrial policy and S&T policy. He was the first director of Chula Unisearch, a business-oriented commercialization unit of Chulalongkorn University and the director of the S&T Development Program at Thailand Development Research Institute. In 1997, he joined the National Science and Technology Development Agency (NSTDA) of Thailand as co-director of the APEC Center for Technology Foresight, and acting director of the Science, Technology and Innovation Policy Research Division and retired as the vice-president for policy. He is currently a senior advisor to the president of NSTDA.

- new diseases such as SARS and bovine spongiform encephalopathy (BSE) with variants such as H5N1;
- infections becoming resistant to treatment (e.g. tuberculosis and staphylococcus aureus);
- zoonoses: i.e. infections transferring to humans from animals, these include: SARS, avian influenza, plague etc.;
- HIV/AIDS, tuberculosis and malaria;
- epidemics due to plant diseases;
- acute respiratory infections;
- sexually transmitted diseases; and
- animal diseases.

These categories are not mutually exclusive but illustrate the wide range of threats.

The world health sector continues to seek new technologies and approaches which are needed to combat these threats, to reduce costs of treatment and to improve the human and animal health situation in both developed and developing countries. For example, recognition of the role of information technology (IT) provides a powerful driver of change in approaches to biosecurity when linked to genetics, biotechnology, nanotechnology and bioinformatics.

Cross-disciplinary and 'converging' technologies

Recently the concept of cross-disciplinarity, that further develops into 'converging technologies' has emerged in the US and in Europe. It emphasizes productive interactions between previously separate fields of research and technological development. Such shifts can result in new technological possibilities, with potentially revolutionary impacts associated with changing innovation patterns, industry structures, and broader developments in society.

It has been proposed that a new paradigm is developing in the 21st century based on the combination of nanotechnology, biotechnology, IT and cognitive sciences (NBIC) and that these converging technologies could radically change society, economy and culture in the next 20 years.

Areas suggested include:

- societal productivity;
- security from natural and man-made disasters;
- providing sustenance for an ageing population;
- combating environmental degradation;
- promoting sustainable development; and
- creating capabilities for managing international crises.

In the US the term 'converging technologies' was first used at a 2001 workshop organized by the US National Science Foundation and the US Department of Commerce entitled 'Converging Technologies for Improving Human Performance'. This workshop proposed the concept of NBIC and discussed possible applications to human health and performance. Several conferences on specific applications have since been held in the US (Roco and Bainbridge, 2002).

In Europe the concept of NBIC was studied by a High-Level Expert Group which produced a report (Nordmann, 2004) directed to the application of converging technologies to development of a European knowledge society. This report contains the pragmatic definition:

> Converging technologies are enabling technologies and knowledge systems that enable each other in pursuit of a common goal

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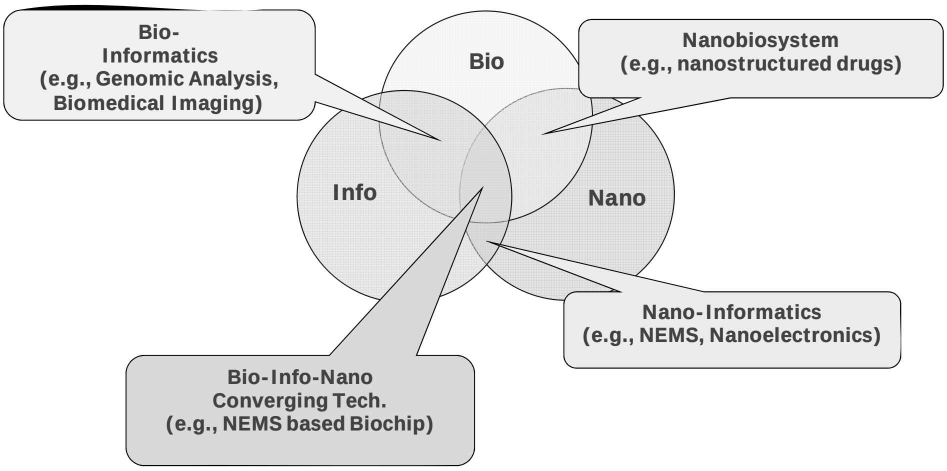

Figure 1. Examples of converging technologies, APEC Center for Technology Foresight (www.apecforesight.org) © 2006
Source: Phucharoenchanachai (2005)

The concept has been extended in the European Union's Seventh Framework Program to the possibilities at the interface of micro–nano systems and the living world. Figure 1 illustrates how nanosystems, biosystems and IT can interact in biomedical–biosecurity applications. In the present study we have applied the concept of converging technologies, particularly the pragmatic European definition, to combating EID. The study has highlighted the importance of interdisciplinary approaches that cross traditional intellectual boundaries when dealing with EID.

The result of this 'converging' approach is to be shown in this paper in the context of the cross-boundary Asia-Pacific regional setting. This double cross-border dimension is crucial to this paper and will have important methodological implications that eventually bring about a clearer identification of 'technology roadmaps'.

The technology roadmapping method has been used in the present authors' previous region-wide studies (APEC CTF, 2006). The new challenge in the present study is the roadmapping of converging technologies within the diversity of the Asia-Pacific region.

Scope and main insights

Better understanding of patterns of infectious diseases needs input from anthropology, economics and climatology supported by statistics and mathematics. The mechanisms of animal–human transmission need input from medicine and veterinary medicine coupled to virology, bacteriology, mycology and parasitology. Vaccine development and delivery can be speeded up using genetics, nanotechnology, molecular biology and bioinformatics. Moreover, health systems research using social sciences, epidemiology and anthropology is needed to understand how new technologies can be used most effectively from the viewpoints of the needs, expectations, capabilities, and cultural sensitivities of the end users.

This paper describes the conduct of this regional foresight project using a combination of foresight methods. Within the scope of existing and new technology development to combat EID, the study provides evidence of how the FTA can address societal issues and challenges, and have impacts on decision-making and actions in the private and public sectors through cooperation over a wide geographical area, specifically the Asia-Pacific region in the next decade and beyond. The key insights include: the mapping between key technologies that should converge in each stage of the EID life cycle, and the roadmaps to develop those technologies that respond to user requirements.

Methodology

Conduct of the project: overview

The project was organized into two phases. Phase I was designed to identify the potential issues related to EID. Those issues included: the trends of potential infectious diseases, the timing of the emergence of those diseases, the level of severity of the impacts from the spread of those infectious diseases to communities etc. Phase II was designed to take the findings from Phase I to determine the possible preparation for the future research and development (R&D) needed to manage, prevent, or combat EID.

To complete the objective in Phase I, a combination of literature review/bibliometric analysis and online surveys were conducted to preliminarily capture the trends of infectious diseases. The publication trends were analyzed by using the medical databases of MEDLINE, to present the potential trends of EID. Then, an online survey using the network of experts in APEC was launched to involve international experts in reviewing the identified trends of EID. When the survey had been completed, a face-to-face workshop for scenario planning was organized.

In Phase II, the objective was to determine directions for future R&D so that APEC member economies can ready themselves to respond to the region's needs. To achieve this objective, the technology roadmapping technique was applied to analyze the linkage between the development of supporting technologies and the future changes in medical requirements in each research domain as identified in Phase I.

At the end of Phase II, a final symposium was arranged in Bangkok in December 2007. Approximately 60 experts from over ten APEC economies, who covered many disciplines and sectors, discussed the preliminary result of the project and shared a longer term perspective to enhance the region's capacities to contribute to the successful prevention and management of EID. Information flow through the two phases of the project is shown in Figure 2.

Scenarios

We used scenarios in attempts to develop internally consistent stories about possible futures (Tegart and Johnston, 2005) where EID become a threat in the Asia-Pacific region over the next decade and beyond.

Thirty three experts from seven economies met in Thailand in February 2007 to develop scenarios for the future of EID in the Asia-Pacific region. After keynote speeches given by speakers from Rand, IBM, Oracle, and the Australian Biosecurity Cooperative Research Centre, the experts were organised into smaller groups. The groups identified key drivers of future change relevant to the study, and the uncertainties influencing these drivers were considered. Self-consistent scenarios were then constructed for an agreed time in the future. Based on the scenarios derived in each group, participants were asked to identify potential technology applications that could be used to prevent or reduce the impact of the crisis as described in each scenario.

Technology roadmapping

The structure of the roadmaps used in this study was designed by adapting from the generic format of a product/technology roadmap (Phaal *et al.*, 2004). The basic elements of a generic roadmap representing market, products, technology, R&D programs, and resources, were changed into the elements listed below:

- medical requirements and users requirements;
- development of technologies supporting the requirements;
- key technical and policy challenges that could

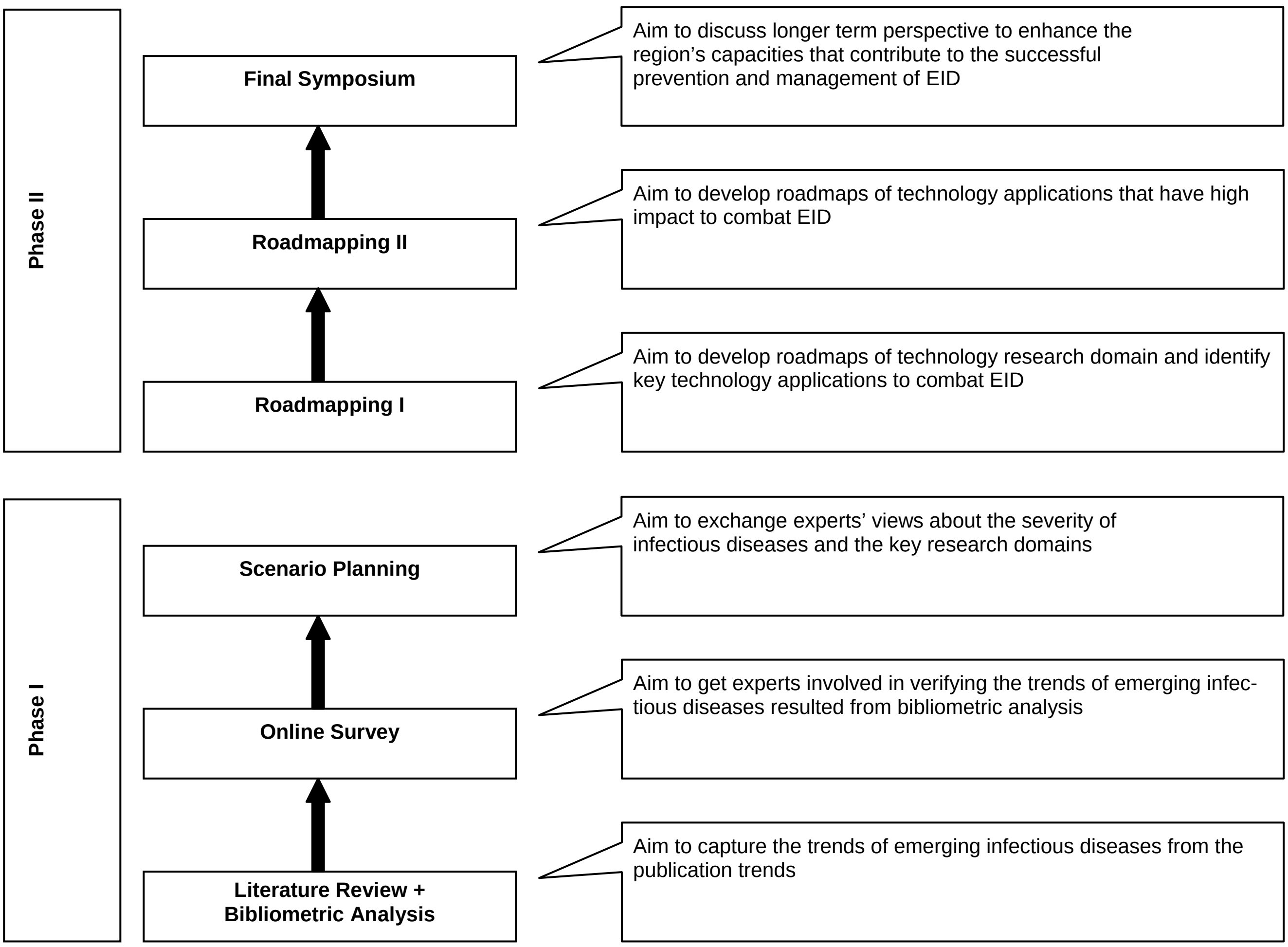

Figure 2. Information flow through the project

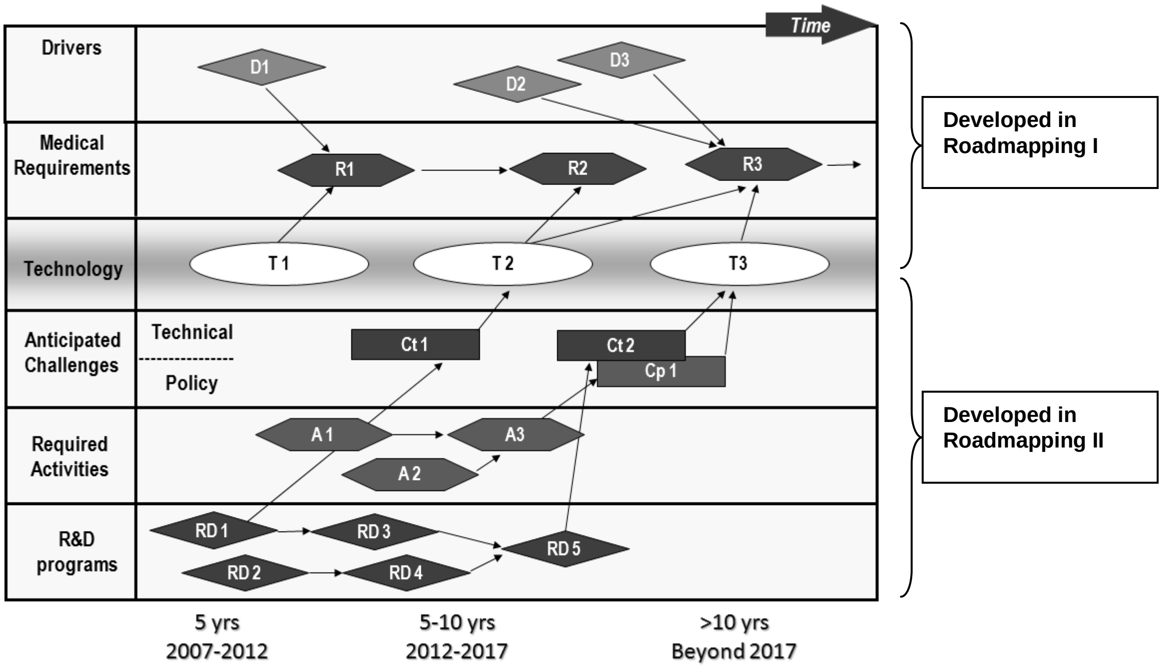

Figure 3. Structure of technology roadmaps

possibly hinder the progress of technology development; and

- R&D programs/activities required in delivering the desired technologies.

The time frame of the roadmaps was divided into three periods: short term (2007–2012), medium term (2012–2017), and long term (beyond 2017). The structure of the roadmaps used in this study is shown in Figure 3.

Two roadmapping workshops were organized in Tokyo in Japan on 22–24 May (42 experts from nine economies) 2007 and in Taipei, Chinese Taipei on 24–26 October 2007 (41 experts from eight economies). Experts discussed the future changes in medical requirements in each research domain, the types of supporting technologies needed, the key challenges that could possibly hinder the development progress, and R&D activities.

Results and policy impact/implications

Scenarios and EID life cycle model

The scenario workshop listed key drivers for EID in the areas of social, technology, economics, environment, and politics (STEEP). It also identified key uncertainties such as massive natural disasters, man-made global security issues, and unpredicted breakthrough technologies. These resulted in the following four distinctive scenarios:

- Scenario 1: *Malaria in Miami 2017*. In February 2015, a family arrives in Miami, Florida from tropical Latin America. A little girl was infected with an unknown strain of malaria. She had been bitten by carrier mosquitoes. There is no experience or history of treating this disease in Miami so disease spreads. Some deaths occur. No treatment is available and social unrest begins.
- Scenario 2: *20,000 people now confirmed dead from mystery disease.* Recently, 20,000 people in Bangkok have been reported dead from a mystery disease and more than 50,000 are sick. Two weeks ago, a large number of birds were found dead throughout the city. The resulting chaos has been the worst in the history of Thailand. Hospitals are overwhelmed with people claiming to be sick. The economic consequences are severe with businesses unable to operate. Tourism has plummeted and retailers are facing bankruptcy.
- Scenario 3: *Mysterious death* Mysterious deaths were occurring in almost every economy around the world. 5000 people were reported to have been infected by the virus. The death rate was low because the disease is thermo-sensitive and only becomes virulent in a hot climate. A range of technologies was put to use to stop the virus. One year later, scientists revealed that the disease was now under control and a vaccine was widely available to prevent its spread.
- Scenario 4: *Emerging rainforest syndrome*. An epidemic, of unknown cause, occurred in ten countries. After tracing back for two years, it was found that it was an unknown illness showing cold-like symptoms followed by flu-like symptoms and severe gastrointestinal distress, leading to death in 20% of the afflicted patients within two weeks. Those who survived the initial outbreak have since been transmitting the disease to others.

The scenario discussions revealed an EID life cycle model (see Figure 4), with four stages from preventive measures to surveillance and detection to treatment and prevention of spread. The model was

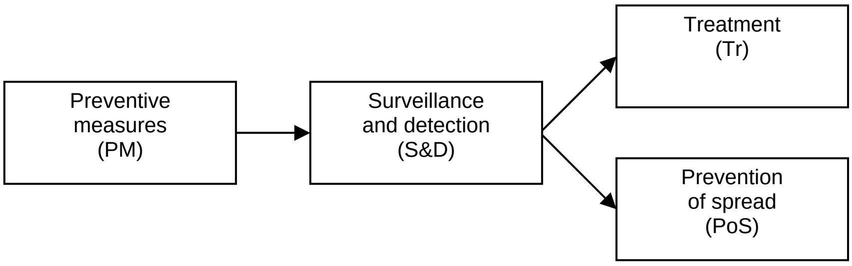

Figure 4. EID life cycle model
Source: Adapted from presentation by Dr Silberglitt (Rand Corporation, 2007)

proposed at the workshop by Dr Richard Silberglitt, a participant from Rand Corporation, USA (Phaal *et al*., 2004).

According to the model, technological approaches can be used to combat EIDs at every stage of their life cycle, from preventive measures such as vaccines to biosensors for surveillance, bioassays for detection, drugs for treatment, and filters, membranes, and fabric coatings for prevention of spread.

A key area of interest for the project is how technologies can converge to contribute to the overall capabilities for more effective applications in biosecurity and EID management in the four designated life cycle domains. Examples include:

- Preventive measures (PM), which is the stage before the emergence of EID. This covers technological approaches such as use of mosquito nets and insecticides in the case of malaria. Future measures could include a preventive vaccine and new approaches to control the vector.
- Surveillance and detection (S&D) is the stage after the emergence of EID. Current S&D includes diagnostic testing and monitoring of cases by person/place/time characteristics. Future diagnostic or communication technologies could potentially improve upon the likelihood and timing of diagnosis and reporting.
- Treatment (Tr). Current treatment options include drugs such as artemisinin-based combination therapies. Future drugs could potentially be even more effective and cheaper.
- Prevention of spread (PoS). PoS include procedures to limit the transmission of the parasite, for example using animal tracking/monitoring.

Future decisions regarding interventions should use all available information about the disease and possible interventions, together with current data from sensors and assays, health clinics, hospitals, and other sources, to estimate the severity of disease effects if no action were to be taken, the time window for effective intervention, and the efficacy of possible interventions.

Since the scenario workshop, this EID life cycle model has been employed throughout the project as the structure for discussions in the technology roadmapping workshops in both Japan and Chinese Taipei and the final symposium in Bangkok.

Technology roadmaps

Using inputs from the scenarios and the EID life cycle, experts at the following first technology roadmapping workshop have identified key domains of technology research, namely ubiquitous computing, treatments, and diagnostics, as having a high impact on combating EID and achieving biosecurity. Results were analyzed and presented as shown in the following tables. The key user requirements were identified for the three technology research domains. Table 1 shows one example: the key user requirements for diagnostics domain. Recommendations for this research domain are shown in Table 2.

The second roadmapping workshop was organized in order to further develop the roadmaps and

Table 1. Key user requirements in diagnostics

Short term	Medium term	Long term
• Accuracy, no need to refrigerate • Long shelf life • Rapid test • Gives result rapidly • Easy to use in the field • Small sample consumption • Reliability • Individual • Information for decision at national level • Sharing intellectual property and experience	• Individual • No physical burden • Test without pain • EID education • Fast, no repetition • Cost: cheap • No physical burden	• Cost: cheap • No physical burden • Continuous microbial monitoring system

Table 2.

Short term	Medium term	Long term
• Improving database of genome, proteome of causative microbe • Need to have international/domestic system for sample delivery	• Research on personal diagnostic devices • Need to solve problem of benefit sharing	• Research on field diagnostic devices • New light source for internal body scan • Visualization of pathogens • Method to detect infected cells

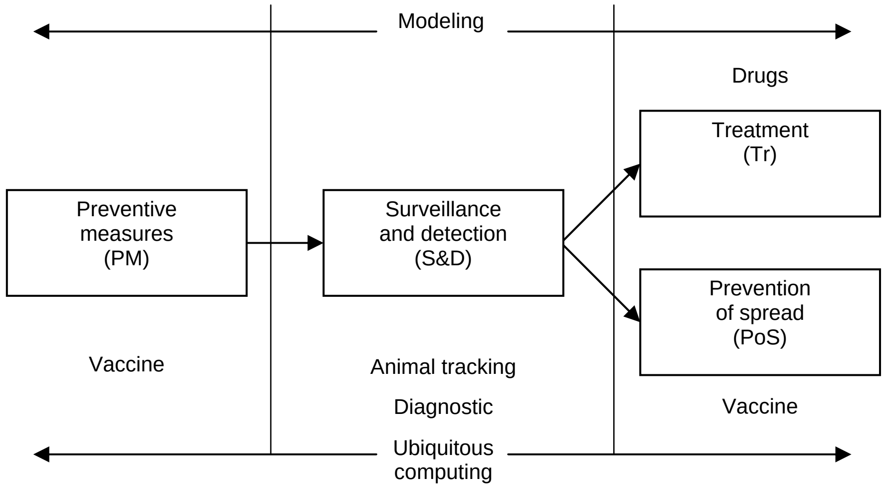

Figure 5. Contribution of technologies to combating EIDs

find more technology applications. The additional technology applications identified were: modelling, vaccines and animal tracking. The discussions at the workshop revealed their inter-relationships both with one another and with the three domains of technology research identified earlier. The role of technology convergence as the key to success in developing the technologies was further confirmed.

All the technology research and application domains identified in the roadmapping workshops fit with the life cycle model (see Figure 5). In keeping with the theme of converging technologies, there are links between all of the technology domains as shown earlier in Figure 4.

To better illustrate the specific roles that technologies can contribute in combating EIDs and achieving biosecurity, this paper gives an example of a diagnostic technologies roadmap (Table 3) as one among the six technology roadmaps developed in the study. Table 3 shows the landscape of diagnostics technology application as seen from both the user's and the technology developer's point of view. Challenges and necessary collaborations are also shown with respect to the short-, medium-, and long-term time horizons.

Diagnosis of infectious diseases is usually done by detecting causative agents (virus, bacterium, etc.) and/or antipathogen antibodies. The former includes antigen detection, genetic, and cultivation methods. Diagnosis plays a critical role in the treatment of disease and in developing response strategies. In an outbreak situation, vaccination may need to be accompanied by a diagnostic test that can discriminate between the response to a vaccine and a natural infection. Appropriate diagnostic technologies are also critical for surveillance programs. In some cases diagnostic technology also plays a crucial role in the prevention of spread.

Policy implications

With strong user inputs in scientific and management issues, the foresight project appears to have high potential to inspire and influence decision-making regarding EID and biosecurity throughout the Asia-Pacific region. Such a continuity of effort to disseminate the outputs of the project and inspire other activities during the later stages of the project and after its termination is usually called 'post-foresight engagement activities'.

During this project many fruitful discussions took place, suggesting potential activities that could have a high impact in efforts to combat EID. The project was announced concluded in late 2008 and the full report (APEC CTF, 2008) with policy recommendation was presented at the 34th APEC Industrial Science and Technology Working Group Meeting held in March 2009 in Mexico. Elsewhere the report was disseminated throughout the Asia-Pacific region and also to non-APEC members such as the UK who also participated in the project. Even before the project's conclusion a number of activities related to the foresight project had been initiated, that also raised the awareness in biosecurity throughout the region. These included:

- The Rand Corporation, who participated in the key events of the project, has proposed a decision model to identify and evaluate an optimum mix of interventions and measures for a specific disease, such as improvements in health infrastructure, which can concurrently benefit more than just a single disease. The model will take into account the existing situation on the ground, evidence-based metrics of coverage and efficacy, financial requirements, and the intended time horizon. The proposal is being considered by the Rockefeller Foundation for funding, with potential involvement of the APEC Center for Technology Foresight and its partnering scientists. It is hoped that eventually the outcome of this project will assist developing APEC member economies in order to optimize the research budget and set policy directions in an effective manner.
- A discussion which developed mainly in the diagnosis roadmap suggested that a new network

Table 3. Roadmap for development of EID diagnostics

	2007–2012	**2013–2017**	**Beyond 2017**
Users' requirement	Validated, easy to use in the field or local site, low cost, suitable for developed and developing countries, no cold chain required	Simultaneous, low opportunity cost testing for many infectious agents	Personalized medicine with testing linked to information networks and personalized treatment
	Higher sensitivity and specificity	Ability to test large numbers of people in a noninterventionist manner	
		Broad screening tools	
		Improved border biosecurity	
	High throughput technologies	Rapid pathogen genetic characterization, high level of biosecurity	
	Access to latest technologies	Automated data collection and analysis	
Technology			
	Towards low cost, high sensitivity and specificity, rapid, multi-agent diagnostic devices linked to automated data collection and analysis →		
Local site	Lateral flow and other point of care devices, low cost	Low cost tests of greater sensitivity, gene amplification	
Regional health centers		Screening technologies for airports, thermal, chemical	Chemical sensing
International institutions			
	Rapid high throughput systems, high polymerase chain reaction capacity	High throughput genetic sequencing	
		Multiplex testing	
	Access to latest and developing diagnostic technologies	High-level investigative capacity and capability	
	Validation processes established	Information collection and sharing system from the local diagnostic systems through to the international institutions	Personal diagnostic devices, implantable or wearable bio-sensor -transmitter
Challenges: technical, social, economic and political	Sensing systems of adequate sensitivity		
	Low cost, point of care amplification systems		
	Effective networks to collect, manage and analyse data		
	National laboratory hierarchy accepted		
	Acceptance of information collection processes		
	Privacy concerns addressed		
	Use of point of care and personal diagnostic		
	technologies in the community without adverse implications		
	Education and communication to public (so that public understands the significance of EID control)		
	Ownership and sharing of biological material		
APEC collaboration projects	Long-term budget system for EID technology development and deployment, APEC 'Centers of Excellence'		
	Validation standards developed	National (and international) information sharing systems developed	BSL3-4 capability developed*
	Laboratory hierarchy strategy developed		

Note: *BSL3-4 capability developed. A biosafety level (BSL) is the level of containment precautions required to isolate dangerous biological agents in an enclosed facility, level 4 is highest level

system could be based on a fully scientific base, and this should be established as a research and diagnosis center for infectious diseases among APEC economies. This proposed center could be used as a hub of the network, with samples, information and human resources shared by Asian countries. Currently, RIKEN, the leading governmental research institute in Japan, is developing laboratories in collaboration with Thailand, Vietnam, China, Indonesia, India, the Philippines, Zambia and Ghana. Subsequently, Dr Okamoto from RIKEN, who was a key contributor to the foresight project, also addressed the possibility of using one of the RIKEN research bases as an

APEC diagnosis center, combining with establishment of a new network system to utilize other research sites effectively for the benefit of the APEC. In order to make significant progress in combating EID, considerable sharing of samples, people and information will be required. Therefore, this initiative could provide a great benefit among APEC member economies as it would establish strong partnerships within APEC and could also enable African research organizations and researchers to study or analyze local samples collaboratively.

- It was stressed in the meetings/workshops of the project that in order to make the best use of the foresight roadmaps, the results should be disseminated to a broad range of (and certainly to those in positions of authority) stakeholders. In Thailand, Ram Rangsin, a Thai medical expert, has been conducting a project on developing policy recommendations of the EID surveillance system for the Thai government. The findings from this APEC-wide project were shared and information was provided to this surveillance project especially with respect to the technological trends and policy recommendations of technologies in ubiquitous computing, modeling, and disease tracking. Rangsin's project was concluded in February 2009 and has provided policy recommendations to the Thai government (Rangsin, 2009).

Conclusion

Bibliometric analysis and scenarios have been used to study the factors involved in initiation and spread of EID within the framework of the EID life cycle model. These are preventive measures, S&D, Tr and PoS, and to guide the future development of responses in controlling these factors.

The life cycle model can be linked to six significant technology domains: vaccines, diagnostics, ubiquitous computing, tracking, modeling and drugs. Each of these provides opportunities for technologies to converge and make significant contributions to R&D and commercialization of devices and systems. Yet the convergence of technologies will not come in the same form as the convergence in information and communications technologies, but rather different technologies will play different roles and interact in a particular value chain, as shown by the technology roadmaps through the mapping of technology applications with the EID life cycle.

Technology roadmaps have been developed for each of these domains to provide the basis for national and regional strategies for biosecurity and combating EID. The significant findings for each of the roadmaps, from the point of view of convergence, are:

- *Vaccines*: vaccine development, production and delivery are essential components of any strategy to combat EID and must be strongly supported. New approaches based on genetic manipulation and molecular design will allow more rapid development of vaccines.
- *Diagnostics*: a range of tools to enhance capability in these areas needs to be developed specifically for the Asia-Pacific region, particularly focused on low cost, portability and rapid information flow.
- *Ubiquitous computing*: the concept of smarter information collection and management is an integral part of adoption of new processes and tools. Increased effort is needed to improve the automated analysis of surveillance data to enable early detection of outbreaks. IT is an integral part of developments in all the domains.
- *Modeling*: the availability of realistic models can assist policy-makers in developing options for coping with outbreaks but they cannot be used in real time when input data are changing rapidly.
- *Tracking*: miniaturized systems are being developed to track both animals and humans but standards and protocols are needed to enable tracking across national boundaries.
- *Drugs*: more effort is needed on the development of therapeutic drugs for more effective risk management, even for those infectious diseases for which vaccines are available.

The specific combination of methods (bibliometric analysis, online survey, scenario, and technology roadmapping) bears interesting potential and advances important methodological issues in FTA. Bibliometric analysis and online survey complement each other in providing insights which provided scope and focus to the study. The scope and focus were further developed into the context of the future by scenario planning, in which the different technologies have roles in enhancing biosecurity and preparedness for EID. With a clearer context of: where and how different technologies are required by users, what are the necessary R&D issues, the key success factors and the barriers, then the landscape of each technology application domain emerged. To this, the final stage (technology roadmapping) added the details of a proposed 'working plan' that are suitable in different time frames so that decision-makers in each member economy of the APEC could invest in their R&D programs and use to decide on the frameworks of their respective international collaboration strategies.

Hence, the unique contribution of this paper lies in its dealing with cross-disciplinary technologies (converging technologies) in a cross-boundary regional setting (Asia-Pacific). The combination of methodologies used here to overcome obstacles in the double cross-bordering dimension, where the context of technology applications in a multilateral R&D agenda is usually not fully explored. The progress described in this paper has important methodological implications and brings about a clearer identification of 'technology roadmaps' that are to be applied to a wider geographical area and more diverse level of technology capacity and socioeconomic development. It is believed that this kind of comprehensive FTA will increasingly be needed as the nature of the new challenges to humankind are increasingly borderless, while technologies are moving faster towards convergence.

The implication of this project is that it has created a new network of knowledgeable and concerned scientists and technologists in the field of biosecurity in the Asia-Pacific region. This can provide a focus for further cooperation. The APEC structure may provide a route to developing this cooperation by sharing of information, facilities and training in combating EID across the region.

The translation of research outputs into policy is of critical importance. Politicians have to make decisions on the basis of available information, which is often imperfect, and hence the prompt and efficient transfer of information from the research environment into the policy environment is a critical component of effectively combating EID. Particularly in the APEC region, security and EID is given high priority, as was evident in the APEC leaders' declaration (APEC, 2006). However, the application of these new technologies in developing economies needs to be undertaken with great care, recognizing that there are major infrastructural, cultural and social differences. The 'people factors' are crucial features of disease management through all phases of the life cycle model from detection to response. Funding for R&D, considering the EID life cycle, has to be balanced, while networking and technology transfer in certain areas are a viable option.

This project is a contribution to the better understanding of the provision of accelerated technological responses to combating EID and biosecurity in the APEC region and of the role of S&T in providing those responses through the concept of converging technologies. It is only a beginning and there is a need for further action by individual economies and by APEC itself as a coordinating body to ensure that the region is adequately prepared for the outbreaks of EID that will inevitably occur in the future.

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