Evaluation of Livestock I&T System in Respect of Contagious Disease Control Based on Adapted State-Transition Simulation Model

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***Abstract*—Livestock Identification & Traceability (I&T) systems are evolving throughout the world in light of technology advancement. Specifically in China, pig I&T systems are in the midst of transformation. While several obstacles have impeded the desired development of the current two dimensional bar code ear tag system, other more advanced systems are tempted for replacement. Since there is no clear-cut rule for an optimal choice, evaluation can be made to assist in selecting the appropriate one. This study adapted the state-transition simulation model to evaluate the systems in respect of contagious disease control. Preliminary results have shown the superiority of more advanced systems in disease control. More importantly, the simulation results have revealed several conditions in which advancement of I&T systems play a more vital role. The adapted evaluation model can be a useful tool in making optimal decisions, preferably if it is refined with more practical assumptions and specific considerations.**

***Index Terms*—livestock identification & traceability system, pig identification & traceability system in China, evaluation model, contagious disease control, state-transition model**

I. Introduction

Livestock identification was probably first introduced when animal husbandry was developed, as a means of proving ownership. The concept was developed gradually in practice with more formal procedures and more complex systems. Animal identification system is now formally defined by World Organisation for Animal Health (OIE) as the inclusion and linking of components such as identification of establishments/owners, the person(s) responsible for the animal(s), movements and other records with animal identification. Accompanied the development of identification, the concept of animal traceability emerged which refers to the ability to follow an animal or group of animals during all stages of its life [1].

Livestock identification and traceability (I&T) system is hereafter referred in this paper to designate the system for the purpose of identifying and/or tracing livestock. Worldwide livestock I&T systems follow general evolutionary development patterns. Different countries and regions are most likely at different development stages. However, it does not imply that one must experience every step in order to improve. In practice, in determining which development level of system to implement depends on many factors and the interactions between them, such as available resources, objectives, technical feasibility, associated cost, economic consequences, distribution of cost and benefit, possibilities of multiple uses, and so on. The factors may have to be traded off with each other for an optimal decision.

A. *Technical Development of Livestock I&T System*

Means of body markings such as branding by a red-hot iron were in practice for a long time. Earlier in time, marking of animals was not accompanied by written documents. Animals were identified within a small area by simple numbering, for instance, by means of paint marking or tattoo somewhere on the ear or body. Later on, on-body marking was combined with documents to record certain animal characteristics. This was a very convenient and probably only method when technology was inadequate for a better method. With advancement of technology, and increasing demand for automation and traceability, electronic identification methods are developed including electronic ear tags and even injectable transponders.

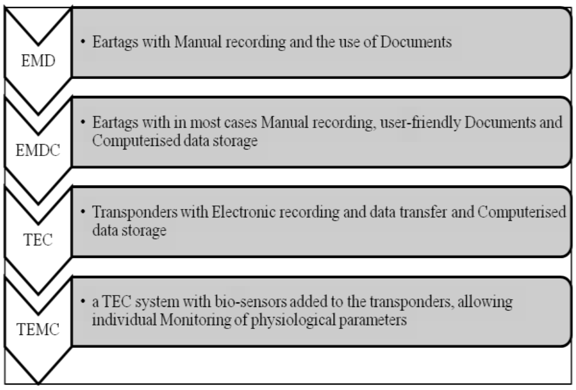

Figure 1. Evolution of livestock I&T system.

Saatkamp, *et al*. [2] proposed the practical concepts and summarised the general evolutionary development of livestock I&T system, which is depicted in Fig. 1. Different countries and regions are most likely at

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different stages. Furthermore for existing systems around the world, it may be hard to label them exactly with one of the four terms in this figure. The evolutionary stages provide a reference point to help understand and compare the numerous schemes all over the world. The detailed goals and problems of each individual system should be explored within its specific context for a comprehensive analysis.

II. Pig Identification & Traceability System in China and Some Obstacles in its Development

Pig identification system in China evolved from tattoo, ear notching to visual ear tag. After realising the possible amount of errors and fault associated with these methods and in an effort to improve the animal husbandry system, the government has started promote two-dimensional bar-code ear tags (2-D ear tags) and made it a regulatory requirement since year 2007. The aim of the 2-D ear tag system is to assist in building an electronic database for fast, accurate and convenient access of pig information. Each pig is supposed to wear the 2-D ear tag at the first time of immunisation at the age of about 60 days. The pig's identity number is in the form of a 2-D bar-code which can be decoded by a reader. An e-file can be constructed for each pig with linkage to the identity number. All the related information of a pig, including birth, its owner, vaccination, movement, etc. will be inputted into this e-file. Whenever the 2-D ear tag is scanned, the reader can show all relevant information along with the pig's identity. Whoever has the authority to access the database can extract the needed information for analysis and control, even at a far distance from the concerned pigs. In this way, traceability of pigs can be realised, provided that errors involved in the process of manual input of information into the e-files can be minimised.

Significance of the development of a computerised database in China should be highlighted. Firstly, it can help simplify statistics management. At end of each calendar year, pig census was carried out by physically checking and counting. The data was passed from the lower levels to higher levels and ultimately the central government. It took large amount of time and labour cost, and may involve plenty of errors. Compulsory wearing of 2-D ear tags and their linkages to a computerised database will save labour work and reduce human errors substantially. Secondly, the information stored in a computerised system will facilitate animal husbandry work at all levels. Another essential function is that better traceability enables more efficient control of animal disease, which is of great concern for various reasons.

China Government Central Document No.1 in 2007 and 2009 both raised the explicit requirements in the promotion of traceability system using 2-D ear tags. Up to date, the enforcement did achieve a quite satisfactory rate of wearing, ranging from 80% to 90% in most provinces. There are ongoing efforts nationwide to obtain a higher wearing rate of greater than 90%. As required, when the pig is slaughtered or died from various reasons, the 2-D ear tag has to be de-registered. This part is a weak point in the current system as the de-registration procedure is rarely carried out. This will cause severe problems in data management in the future since the number of pigs kept in the database will increase infinitely.

Despite the increased rate of wearing 2-D ear tags, progress of construction of the e-files and electronic database is rather pessimistic. The animal husbandry service should have been a lot easier if there is such a computerised database. The reality is that their work is still mostly based on paper documents, including those related to the pig identity and pig's information. The 2-D ear tag is at present just a matter of formality. The reader is used to get the pig's identification number, without the construction of e-files and electronic database behind or without appropriate application of the database at least.

A. *Some Obstacles in the Development of Livestock I&T System in China*

Several problems exist which prohibit the ideal advancement of the identification and traceability system. The ear tag may not possess high quality regarding ease of wear, water proof, ease of reading, etc. The awareness of the usefulness of such computerised database is very low among the lower-level service providers and thus low initiatives at the lower level. In more rural areas, service providers may not know how to use the reader and input data, and may easily incur errors. Furthermore, there is lack of support from some farms and rural households.

While most of these problems can be overcome gradually through extensive education and publicity, there are two major technical reasons for the current unsatisfactory development. On the one hand, it is due to issues related to the reader which is needed to de-code the 2-D bar-code. On the other hand, network and information flow is pre-requisites for the system which however has some unsolved issues.

2-D bar-code reader issue: Although the implementation of 2-D ear tags started a few years ago and is widely known now, the practice is still classified as trials. The system and its associated technology are not mature enough. Ministry of Agriculture (MoA) is in charge of the development of the identification and traceability system, while the funding is provided by the National Development and Reform Commission (NDRC). MoA has separate activities in collaborating with some companies or inviting bids from contractors to develop the smart readers. The funds provided by NDRC are inadequate for these readers due to the high cost of the reader itself and a lack of proper coordination between the two agencies. One village in Sichuan Province for example was provided with only 6 such readers in average. In fact, many parties in the animal husbandry service chain, such as the owners, veterinarians, bureaus responsible for the animal epidemic prevention, quarantine and surveillance, etc. do need the readers to obtain information and input further information for completing e-files and subsequently the computerised database. The high cost of the readers and inadequate funding do not support the wide distribution of the readers to all relevant parties. With the current insufficient supply of readers, therefore, the information is not complete and its flow is not continuous. Additionally, there are certain quality and reliability problems with some readers. The desirable goal of building pigs' e-files and electronic database is thus not fully reached.

Network design issue: The second obstacle in the establishment of a good identification and traceability system is the network design. The network and data flow service is provided by China Mobile Communication Corporation. The primary goal is the construction of electronic database. However, the task is for a central database only, at least at the current stage. It means that all the data and information collected is to be uploaded to the central level only, bypassing the lower levels of town, county, city and province. One aspect of the problem is that individual data uploading cause very severe problem of "data transport jam". If instead, data is uploaded to a smaller region level and subsequently uploaded to higher levels in forms of data packets, data traffic can be a lot easier and faster. The other result of information bypassing the lower levels is that the lower-levels personnel involved have no motivation to support so. There is no database to be expected for the county-, city- and provincial-levels. The lower-levels are not supposed to have the authority to access the central database. This is true at least for the current development. Lack of incentives and support from the bottom, it is difficult to build such an ideal central electronic database. The other way around, the database available only at the central level is unable to efficiently support the lower-level authorities in carrying out their service work.

III. An Improvement of the Current 2-D Ear Tag System or a New Electronic Regime?

Attempts are being made to improve the current 2-D ear tag system, through extensive publicity and education, also technology research and promotion. These include wider coverage of 2-D ear tag use, greater availability of 2-D code readers which are more cost-effective and user-friendly, other hardware and software in building the computerised database. Combining all these, it is aimed to really realise systematic collection and management of livestock data. At the same time, with technological advancement, electronic transponders became technically feasible to be used in this field. Furthermore, they may provide more benefits which are increasingly being recognised by the government and some large-scale farm owners. Therefore, there are proposals indeed to develop a new electronic regime for livestock management. This ranges from the replacement of 2-D ear tag with injectable electronic transponders to additional bio-sensors that can be added to the transponders. These initiatives are especially pioneered by private parties.

The answer to the question of which system is more preferable is not so clear-cut. More benefits come certainly at the expense of higher cost. How to make an optimal decision depends on the extent to which the costs can be justified by its benefits.

Qualitative characteristics matrix: A brief comparison of the three systems is made in Table I using a qualitative characteristics matrix. This table serves as an intuitive checklist of I&T system against two qualitative dimensions. Effectiveness in this context means the extent to which the system could potentially achieve the objectives of identification and traceability of individual animals, whereas efficiency is gauged in terms of data flow from collection to utilisation. For the three systems, ranks of 1-3 are assigned for each whereby 1 stands for the best performed one on that specific dimension. For certain qualitative characteristics whereby systems do not differ so much, equal rank is assigned for them. The measurement using numbers 1-3 here are ordinal scales, with the system being ordered in respect of the specified characteristics. These ranks are brief indicators of their respective advancement and their relative performance.

TABLE I. Qualitative Characteristics Matrix

Effectiveness		EMDC	TEC	TEMC	Efficiency		EMDC	TEC	TEMC
Individual Identification	Correct recording;	3	1	1	Data Collection	Fast;	3	2	1
	Tamperproof;	3	1	1		Accurate;	3	2	1
	Permanency; Etc.	3	1	1		Automatic; Etc.	3	2	1
Events Recording	Birth/import entrance;	3	2	1	Data Transfer	Fast;	3	1	1
	Death/export exit;	3	2	1		Reliable;	3	1	1
	Vaccination/medicine; Etc.	3	2	1		Automatic; Etc.	3	1	1
Movement Tracking	Farms;	3	2	1	Data Storage	Secure;	3	1	1
	Transportation companies;	3	2	1					
	Assembly places;	3	2	1		Replicable; Etc.	3	1	1
	Slaughter houses; Etc.	3	2	1					
					Data Supply	Available;	3	1	1
						Accessible; Etc.	3	1	1

EMDC: For the system using 2-D ear tags, it can be categorised as the EMDC system, where the biggest improvement from the most traditional system is the implementation of computerised data storage. It affords a far more efficient process of data utilisation compared with the use of paper documents. The use of 2-D code may also reduce the chance of fraud. However, the problem with visual ear tags persists. Drawbacks include many losses of ear tags, poor quality and low speed of the data collection. Since the 2-D code is read for identification only, extensive labour work is still required in manually recording relevant data, transferring into electronic data, and manually inputting further information. Errors can easily occur in the process.

TEC: The first alternative is to replace the 2-D ear tag with electronic ear tag or injectable transponder. Electronic identification can further reduce the chance of fraud. However, electronic ear tags have similar problems with visual ear tags. Theoretically, injectable electronic identification can resolve the problems of wearing ear tags. Therefore, it is assumed transponders are better off in respect of the three identification characteristics items. Since some information can be obtained electronically and errors due to manual recording can be reduced, the purpose of events recording and movement tracking ranks better than the 2-D ear tag system. Similarly, for the efficiency dimension items, electronic transponders should outperform with better data collection and subsequent retrieval and utilisation of the information.

TMEC: At the same time of proposing TEC system, TMEC system is undeniably more desirable which adds monitoring functions with attached bio-sensors on the transponders. The key attributes of livestock can be monitored continuously and recorded automatically. The driving force, on the one hand, comes from farm management. It has been expected that a farmer will get more profit from identification and monitoring system than from identification only. On the other hand, if the cost of electronic identification is incurred already, integration of the monitoring functions with identification can justify the high cost or recycling of the electronic ID ear tag. TMEC systems would possess the capability for quicker identification, automatic recording and reporting to the database, and for automated data management. Therefore, this system is thought to be supreme with respect to all these qualitative characteristics. The most profound leap is its capability for more automation in data collection, and thereafter better traceability.

A. The Primary Concern for Contagious Disease Control

The first analysis component in making decisions against which system is more appropriate is its impact on disease control. Disease control is a primary driver for the establishment of livestock traceability system. With the ability to identify each individual animal and track its movement, the source and the extent of the disease outbreak can be ideally figured out. It could allow quick response and help in formulating zoning strategies. With addition of the monitoring functions to the identification system, animal health conditions can even be under surveillance in a continuous manner. It enables early detection and notification of any disease outbreak, and may prevent outbreak completely at the very early warning stage.

Up until the early 1990s, the animal health situation in Europe was considered far from satisfactory. However, at present circumstances, it is recognised a quite high and uniform level of animal health throughout Europe. Key animal diseases such as rabies, foot and mouth disease (FMD) and classical swine fever (CSF) are either eradicated or under control. This satisfactory condition results from Europe-wide efforts in terms of political commitment, financial assistance and trade incentives, the single biggest contributory factor of which is the implementation of identification and traceability systems [3]. Amongst all these factors, Belgium and the Netherlands stand out as they have put into many efforts in the research and practice of their Identification and Recording System. The system was developed and improved with primary focus on the control of contagious diseases, such as FMD and CSF. Several studies in North America [4]-[6] have also been carried out to examine the benefits of livestock traceability systems in controlling FMD for the purpose of determining the appropriate system or improving their current systems.

IV. State-Transition Simulation Model Adapted for Use in China context

In earlier days, a few studies [7]-[9] had used the state-transition model for modelling different livestock diseases. Saatkamp, *et al.* [10], [11] had later applied the state-transition simulation model to evaluate the epidemiological impact of Belgian Identification and Recording System on the control of classical swine fever. Their study was essentially based on Miller's research [12] which modelled epidemic foot-and-mouth disease and was applied to the USA situation. This model was initially applied in modeling livestock epidemic disease due to its various advantageous properties. It was developed from a Markov Chain model but more general thus more appropriate for the situation [12]. Additionally, it is easy to program and cheap to run. More recently, the North American Animal Disease Spread Model is also based on the concept of state transition model [13], [14].

This model was concluded as a very useful tool for decision support in relation with the livestock I&T system. The state-transition model is therefore adapted to be used in the China context. The general aspects of this model will be reviewed as follows. Those factors that are specific to our context will be specially pointed out and adapted accordingly.

In carrying out this simulation model, three basic elements were pointed out in Saatkamp, et al.'s studies [10], [11]:

- A finite number of exhaustive and mutually exclusive states which describe the distribution of the system;
- Transitions which describe the probability of going from one state into another;
- A discrete time step.

The *basic unit* used in this model is herd or premise, in this case, large-scale pig farm. Farms are set to be in one of five mutually exclusive *states*: Immune, Susceptible, Carrier, Outbreak, and Removed. This is distinct from Saatkamp, *et al.*'s model assumptions about states, whereby "Immune" is not considered as preventive vaccination was stopped in the EU since 1991.

Transition probabilities refer to the probabilities of changing from one state to another. These transitions are reflected in the transition matrix with important transition routes shown in Table II. For each row, transition probabilities will sum up to unity. At the start of the modeling process, the proportions of herds in each state will be presented or calculated. After multiplying the probability vector, the transition matrix can be updated with new proportions of each category. The important transitions probabilities are referenced from Saatkamp, et al.'s work, while the probabilities involving the "Immune" state are modified and added to the model.

Time step is set to be one week in this work, which is shorter and hopefully will be more indicative. This model is a discrete-time process, and therefore the calculations are done at end of each week.

TABLE II. STATES AND TRANSITIONS MATRIX

From \ To	Immune	Susceptible	Carrier	Outbreak	Removed
Immune	Remaining Immune	Waning Immune	--	--	--
Susceptible	Effective Vaccination	Remaining Susceptible	Infection	--	Pre-emptively Removed
Carrier	Convalescent Immunity	--	--	Becoming Outbreak	Contact Slaughter
Outbreak	Convalescent Immunity	--	--	Becoming Outbreak	Outbreak Slaughter
Removed	--	Restocking	--	--	Remaining depopulated

An important variable is used in the state-transition model which is termed as *Dissemination Rate (DR)*. It represents the average number of herds or premises to which agent is delivered by each infected herd and irrespective of that herd's status [12]. In another word, it refers to the propensity to spread to other herds. Dissemination rate is not easily calculated but depends on a number of factors, as shown in Fig. 2.

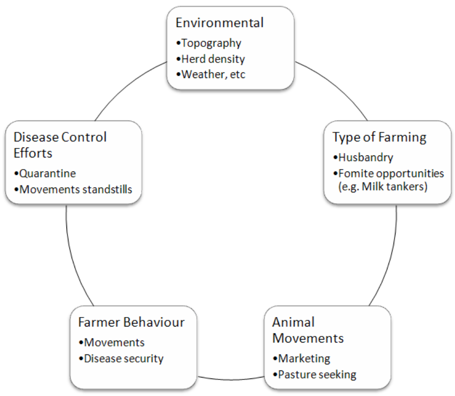

Figure 2. Determinants of dissemination rate [12].

TABLE III. ASSUMPTIONS OF MAXIMAL DISSEMINATION RATE

Week	$DR_{max,t}$	$Log_{10}(DR_{max,t})$
0	2.0	0.3010
1	1.7	0.2304
2	1.4	0.1461
3	1.2	0.0792
4	1.0	0.0000
5	0.85	-0.0706
>=6	0.75	-0.1249

A very important empirical evidence from previous studies revealed that DR decays exponentially towards a value of about 0.75 [12]. A more indicative enlightment is that $\log_{10}$DR can be decomposed into two linear regressions, the latter part of which can be regarded as horizontal. Therefore in this study, it is reasonable to assume the Default Maximal DR as shown in Table III. This is a simplified base case than the Belgian study where we do not distinguish the transmission routes. Since assumptions would otherwise be made for each route and summed up as an estimated total DR, it is indeed rationale as a starting point to assume one estimated dissemination rate.

Maximal DR is the theoretical rate at which the disease can be spread out without any notice and control. Besides the self-decaying properties of DR, control measures can help reduce the transmission of diseases. *Reduction Factor (RF)* is therefore introduced into the model to account for the effect of control measures and the functions of livestock I&T system.

Four control measures are considered for the model, which are most commonly carried out in case of any livestock disease notice and outbreak. By each individual control measure, it is supposed to be able to contain the disease spread to a certain degree, keeping all other influencing factors unchanged. The extent to which they can reduce spread is termed in the model as their *Potential Reducing Effect (PRE)*. Their values are shown in Table IV.

TABLE IV. POTENTIAL REDUCING EFFECT (PRE) PER CONTROL MEASURE

Control measures (x)	PREx (in %)
Detecting outbreak herds	10
Pre-emptive removing (1.0km)	50
Protection and surveillance zones	60
Tracing carrier herds	80

An additional factor is needed to calculate RF, which is the *Effectivity Values* for livestock I&T system *(S)*. It refers to the degree of support I&T system can support for each control measure, in order to realise their potential reducing effects. TEMC is considered as supreme in its ability to identity and trace, therefore assumed to be at the perfection extreme with effectivity values of 100%. The values in Table V are used for this simulation model.

TABLE V. EFFECTIVITY VALUES FOR LIVESTOCK I&T SYSTEMS

Control measures (x)	Sx (in %)		
	EMDC	TEC	TEMC
Detecting outbreak herds	50	80	100
Pre-emptive removing (1.0km)	50	80	100
Protection and surveillance zones	50	80	100
Tracing carrier herds	50	80	100

Another important role played by livestock I&T system in help control disease is a matter of time. When there was any disease outbreak, very often it was noticed not immediately but after a while, say To, the time from the original outbreak to the point when it was noticed. Efforts were normally initiated at this time point to take various control measures. At the same time, efforts can be more efficient and effective if it is possible to trace back the original outbreak to assist precise control. Time Tt is needed to trace the disease origin. Therefore, total time elapsed from the original outbreak to the point when the origin is detected is To+Tt, exhibited in Fig. 3.

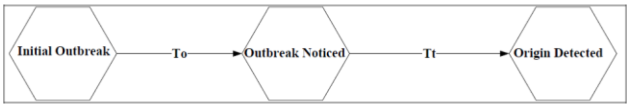

Figure 3. Important timeline for disease outbreak.

However, for the convenience of this study, we use one time period called *pre-period (in weeks)* to specify the properties of the three livestock I&T system in consideration. The assumption is that the disease starts spread at week 0, with no knowledge of its outbreak and spread, no any effort is taken. Therefore disease will spread at the Maximal DR for initial weeks. Upon the end of pre-period, DR can be altered as a combined result of the control measures and functioning of livestock I&T system. These assumptions are reasonable as our base case accordingly to previous empirical studies. TEMC ranks the best in its capability for timely notice and fast trace-back, therefore has the shortest pre-period. *Specificity of tracing carriers (E)* is similar to the concept of precision in tracing carriers which will be useful in calculating transition probabilities in latter parts. Although E differentiates the three systems in their effectiveness and precision in tracing livestock, another variable is purposely used to represent the regional specific conditions affecting the use of livestock I&T systems. A conservative figure of 50% is assumed as the *percentage of potentially traceable* carrier herds with use of I&T system *(Pot)*. These additional assumptions are listed in Table VI.

TABLE VI. MORE ASSUMPTIONS

	EMDC	TEC	TEMC
Pre-period (in weeks)	6	4	2
Specificity of tracing carriers (E)	50%	80%	100%
Pot	50%		

To make above assumptions useful, there are a few equations in the model. Step 1 is used to find each control measure's reducing effect with the use of different livestock I&T systems. Somehow, step 2 looked awkward in generating the total Reducing Factor as a resultant combination of control measures and I&T system. This is referred from the originally Belgian study which was meant to aggregate RF due to its non-linear nature. Last step is to modify the theoretical maximal DR considering various reducing effects. Worth repeating at this time point, within the pre-period, diseases are assumed to spread at its theoretical maximal DR. Until the end of pre-period, interventions will then start and DR be altered by Reducing Factors.

- Step 1: RFx = PREx*Sx (x=1,2,3,4)
- Step 2: RF = RF1+RF2*(1-RF1)+RF3*(1-RF1+RF2*(1-RF1)))+RF4*{1-RF1-RF2*(1-RF1)-RF3*(1-(RF1+RF2*(1-RF1)))}
- Step 3: DRt = DRmax,t*(1-RF)

The heart of the state-transition model is the transition probabilities matrix (Table VII), which quantitatively describe the probabilities of changing from one state into another during one time step. The most important probability in this matrix is the probability of changing from susceptible to carrier which, in other words, is the probability of becoming infected. The same formula is adopted in this study, $P_{su-ca,t} = 1 - e^{-DR(t-1)*Fou(t-1)}$ [11]. Since the category of "Immune" is considered in the adapted model, it is necessary to add a few more variables for consideration.

TABLE VII. TRANSITION PROBABILITIES MATRIX

To From	Immune	Susceptible	Carrier	Outbreak	Removed
Immune	IE1	1-IE1	--	--	--
Susceptible	IE2	$1\text{-IE2-}(1\text{-}e^{-DR*Fou})$	$1\text{-}e^{-DR*Fou}$	--	--
Carrier	Pot*E*IE2	--	--	1-Pot*E	Pot*E*(1-IE2)
Outbreak	E*IE2	--	--	1-E	E*(1-IE2)
Removed	--	--	--	--	--

Effectivity of immunisation (IE): This refers to the effectiveness of general immunisation measures applied for all livestock since new borne as a common health practice. These measures may safeguard the livestock from being affected from most general viruses. The ineffective portion of livestock may be regarded as the initial susceptible population. Its value varies depending on the severity of the concerned disease. For commonly aware diseases, this factor can be close to 100% as livestock are most probably taken vaccines against them.

In contrast, it can be as low as 0 if the disease is completely novel and destructive, and therefore the total population may be susceptible to the disease.

IE1: It stands for durability of the general immunisation measures. In other words, it is the probability of the immune population staying as immune. (1-IE1) is therefore the decay rate of the general immunisation measures which equals the probability of the originally immune population becoming susceptible. This value will much depend on the quality of initial immunisation and the changes of the concerned disease.

IE2: It is referred as the effectivity of specific immunisation measures. Once there is appearance of any concerned disease, vaccination and other treatment measures can be taken to control the disease outbreak and spread. Some proportion of the carrier or outbreak population will turn back into the Immune category. Its value depends on the responsiveness in combating the emerging disease.

Although in previous paragraphs, it is said that control measures will be taken into account at the end of pre-period, the effects of immunisation measures are supposed to affect transition probabilities from the very beginning. There is normally not a clear-cut time point when the disease outbreak is exactly noticed and dealt with immediately. The early impact of any immunisation measure is, in part, to counterbalance the previous assumption on pre-period. It is also reasonable because in reality control measures and immunisation measures are generally taken in a more continuous manner.

With all the assumptions listed above, simulations can be carried out with varying input values. With no real-life data, which is not possible to get the exact figures either, these default values in Table VIII serve for a general purpose to examine the functioning of livestock I&T system in same conditions. Later in the simulations, these default values will be altered in order to see the changes and detect any major sensitivity.

TABLE VIII. DEFAULT MODEL INPUT VALUES

Input variable	IE	IE1	IE2	Week 0 F_{ou}
Default values	80%	90%	20%	0.01

By using these default values, it is assumed moderate level of immunisation preparedness and a moderate disease attack, where starting at week 0, 80% of the population is well immune against the concerned disease. The decay rate of the initial immunisation measures is rather low at 10%. Once there is any outbreak, effectivity of specific immunisation is 20%, which is thought to be rather good recovery from “carrier” and/or “outbreak” population. In addition, it is assumed that the fraction of outbreak is only 1% at week 0. Simulation with the default values is run for 20 weeks.

A. Simulation Results and Discussions

Not surprisingly, TEMC system with best scores in respect of all the qualitative characteristics outperform in its ability to help contain disease spread. The fraction of “Immune” will gradually decrease due to the main factor of decaying immunity. Therefore, “Susceptible” population will increase and reach a stable status. The performance of the three I&T systems look rather homogeneous in Fig. 4, but in fact, better I&T system manages to reach a higher fraction of Immune in shorter time. Interestingly, the proportion of Susceptible is higher with TEMC system although the difference in negligible. This is probably due to the dominant effect of decaying immunity in the assumptions.

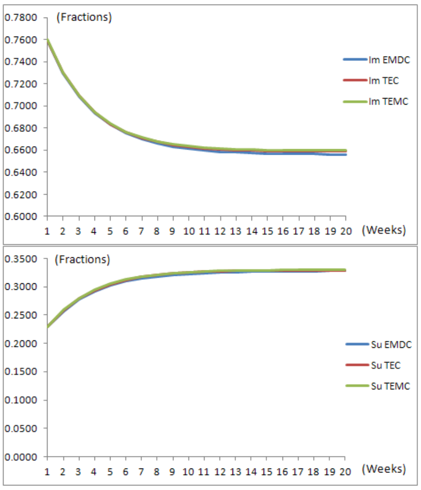

Figure 4. Fractions of immune and susceptible.

The distinction is much clearer when the fractions of the other three categories are examined. It takes much longer time for the EMDC system to help in bringing the Carrier and Outbreak proportion to the minimal. Instead, with the use of TEMC system, the fractions of Carrier and Outbreak reach the steady state of minimal in about 5 weeks. The total population to be removed with TEMC is much less as well. In contrast, the proportion of Removed increases for a longer time and reach a higher level for both TEC and EMDC systems. (Fig. 5)

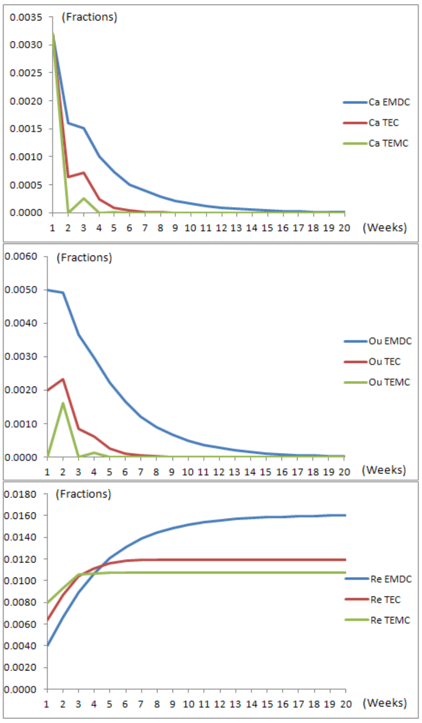

Figure 5. Fractions of carrier, outbreak and removed.

A moderate disease outbreak was assumed for above simulation. The results are fair and reasonable with the expectation that better I&T systems should deliver better disease control results. Next, the input value of $F_{ou}(t=0)$ is altered to be 0.1 to represent a more severe disease attack.

The more severe the disease outbreak is, the more important the role played by livestock I&T systems. When the initial outbreak is more serious, the fractions of Immune decrease to smaller amounts. At the same time, the differing contributions of the three I&T systems become more obvious with more serious outbreak. (Fig. 6)

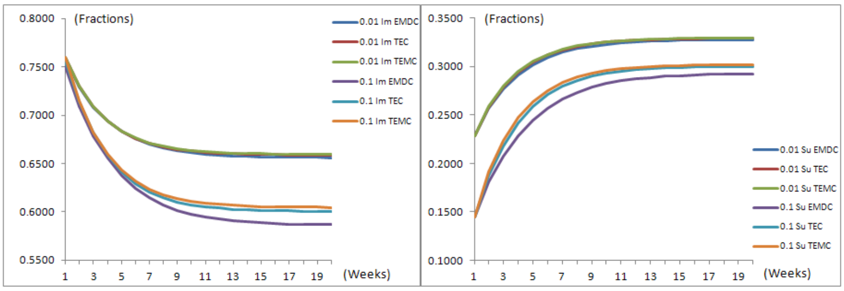

Figure 6. Outbreak 0.01 vs. 0.1(a).

Keeping outbreak figure constant, TEMC system performs the best in containing disease in the shortest time and result in the smallest total number of Removed. An apparent pattern can be viewed from Fig. 7, the disparity of the three I&T systems are more explicit when outbreak figure is set to 0.1 in comparison with outbreak of 0.01. That is to say, when considering potentially rather severe disease, the impact of the choice of the livestock I&T system will be much more significant.

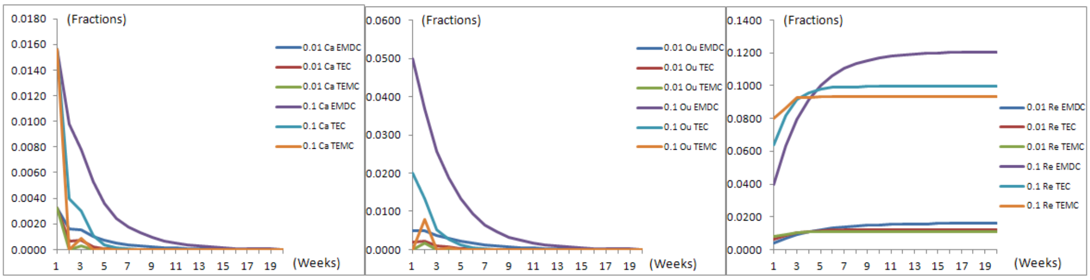

Figure 7. Outbreak 0.01 vs. 0.1(b).

Besides the alteration of week 0 outbreak figure, next attempt is to assess the sensitivity against effectivities of immunisation measures. Setting $F_{ou}(t=0)=0.01$ unchanged in the default model, the three variables of IE, IE1 and IE2 are updated, as shown in Table IX, to reflect better positions in immunisation status. The updated condition indicates better general immunisation measures as a higher proportion is assumed to be immune against the concerned disease. A much smaller decay rate is used which means a higher probability that the originally immune population will stay immune. In addition, for the carrier and outbreak, a higher probability is assumed for them to turn back into the immune category. In summary, the updated values resemble a better immunisation prepared population.

TABLE IX. UPDATED INPUT VALUES

Input variable	IE	IE1	IE2	Terms
Default values	80%	90%	20%	P (poor immunity)
New values	95%	98%	35%	G (good immunity)

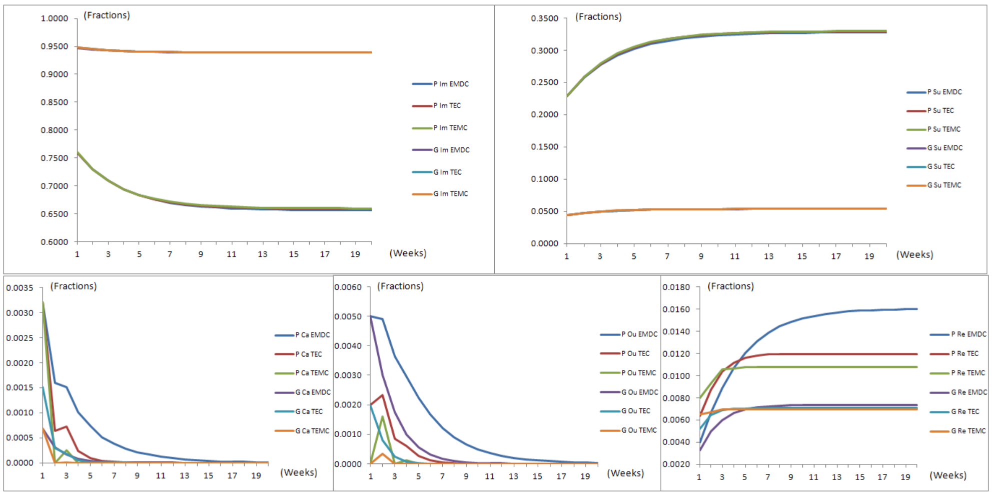

Figure 8. Poor vs. Good immunisation.

Better immunisation status in general and better responsiveness in emergency immunisation measures, by their own means, are more favourable for disease control. This outcome is exhibited as higher fractions of Immune, lower fractions of Susceptible, faster to bring down Carrier and Outbreak proportions, and smaller proportions for total Removed. Fig. 8 also demonstrates that, when immunisation status is set to be lower, the decisions on which I&T system to implement make rather larger difference on the ultimate disease control efforts. In other words, total population affected and the time taken to constrain contagious diseases is more sensitive to the choice of I&T system when the population is less immunisation prepared.

V. Conclusions and Recommendations

Preliminary results above have shown the superiority of TEMC and TEC systems in help controlling contagious diseases. However, what is more important is that this adapted evaluation model can be useful to examine the relative advantages of these I&T systems under varying conditions. When the population is less immunisation prepared, being it either poor general immunity status or poor responsiveness in emergency immunity, and/or when the disease attack is more severe, I&T systems will have a more profound impact on disease control.

If this evaluation model is refined with better assumptions and with more specific considerations, it can be a useful and practical tool in help making optimal decisions on the choice of I&T systems.

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