ABSTRACT

Antiretroviral (ARV) drug is a drug to hinder the development of Human Immunodeficiency Virus (HIV) which causes of Acquired ImmunoDeficiency Syndrome (AIDS). So consuming it for people who infected by HIV or living with AIDS could encourage their long life expectancy, since there are not any drugs has been discovered to cure this disease. Therefore, the demand complexity of ARV drug is largely influenced by infection pattern of HIV/AIDS, requirement of lifetime treatment, impact of Antiretroviral Therapy (ART) program and patient adherence level. So there is a needed for an inventory model that guarantees high service level at hospitals that serve HIV/AIDS medical patient, while optimizing the cost of inventory. In this paper, a new methodology by using a system dynamics approach in designing inventory model for decentralization logistic system in a case of ARV drug based on HIV/AIDS epidemic model will be explained. The case takes place in four state hospitals in Indonesia which conduct a government pilot project for HIV/AIDS prevention on 2009. Four indicators of logistic system have been set up in the Causal Loop Diagram (CLD) that shows the relationship between HIV/AIDS epidemic model and inventory model. Then the CLD will be verified and validated with a series of testing to ensure the model could represent the same behaviour in real situation. In the end, the result and a series of sensitivity analysis show that the inventory buffer policy for hospitals, provincial warehouse and central warehouse will produce the optimal solution.

KEYWORDS

System Dynamics, Logistic System, Inventory Model, HIV/AIDS Epidemic

INTRODUCTION

In the last ten years, a campaign to raise HIV/AIDS ART for millions of people living with HIV/AIDS in countries with limited resources has gained substantial commitments in financing (e.g. Global Fund to Fight AIDS, etc.), operational support (e.g. Joint Program of the United Nations on HIV, etc.) and support the procurement (e.g. Clinton Foundation HIV/AIDS Initiative, etc.). Currently, in Indonesia, composition of the Indonesian population aged 15 years and older, which reached more than 68% (Indonesia Statistics Agent, Indonesia Population projection 2000-2025) of the total population is a susceptible group of contracting HIV/AIDS, to encounter this, dispensing ARV drug for ART is free.
Efforts to increase the coverage of ART services need support of a good logistics system management from any point of distribution to the point of health care units in inventory control systems, information systems management, storage systems and distribution systems. One national program conducted by Indonesian government in logistics management for ARV drug is decentralization logistics system ARV. The decentralization logistic system is chosen because it could solve any problem that centralization logistic system could not solve, such as inadequate to fulfill demand of ARV drug for ART by center, inadequate data quality of reporting and recording in ART, order planning management from ART is not accurate. All of these problem are occurred because ART having experience stock out in infrequent, no clear delivery schedule of ARV drug, ARV drug delivery does not match with the demand requested in number and type of drug, also found some of drug to be expired and over stock because stock of drug incompatible with patient needs and no redistribution management; by looking these problem, it seems to be the epidemic of HIV/AIDS is strongly influencing the demand pattern of ARV drug. Therefore, ideal inventory model based on HIV/AIDS epidemic model which will synchronize supply and demand to reduce inventory throughout the supply chain, and improve services (service level) in ART center or hospital, is a must. Moreover, ARV drug is a drug that requires a high level of patient adherence (95%) in ARV drugs for effective treatment.

This paper mainly has two main contributions. First, it introduces a new methodology in inventory modeling through a system dynamics approach by combining an inventory model and epidemic model, especially for the case of HIV/AIDS epidemic. It happens since despite of there is a lot of system dynamics and non system dynamics literatures pointed a study in inventory modeling related to procurement, production planning, demands factor and supply chain. But most of them are more focused on manufacturing with constant demand characteristics, not the pattern of an epidemic, e.g. the compare between the procurement and inventory control strategies in determining base on the optimal and minimized cost (Van et al., 1996), method of dynamic systems in the same activity in the recycling plant process activity (Polishes and Cheong, 2009), the use of dynamic systems to improve inventory management in a batch-wise complex plant (Lukszo and Christina, 2005), the stability of inventory and production control system by considering the shortage of inventory (Jayedran and Cayu, 2007), a dynamic systems modeling in supply chain management that focuses on inventory decision, demand implication and supply chain form of the model (Angethofer and Angelides, 2000), a model to test different policy priorities in Reconfigurable Manufacturing Systems (RMS) for a variety of different demand scenarios (Deif and Almaraghy, 2007), statistical methods to estimated HIV Prevalence by synthesize results from several sources of data (Yujiang, 2008), the projection of AIDS cases method extrapolation (Pedamallu, 2009; Morgan and Curran, 1986; Karon et al., 1988, 1989), backward calculation methods used to estimate HIV infection rates in the past from AIDS case data and also estimate the distribution of the incubation period. (Ong, 2006; Brookmeyer and Gail, 1986; Gail and Brookmeyer, 1988; Brookmeyer and Damiano, 1989) and a mathematical model for the epidemic of AIDS in Tanzania (NACP, 2005).

Second, in the managerial impact, it could improve the ARV drug inventory decision based on epidemic model, generally for Asia and especially in Indonesia, since the current epidemic model (Asian Epidemic Modeling), used by Indonesia, doesn’t show the impact of different policies as well as biology and significant impact on the ARV treatment policy. Moreover, it could not predict the changes/interventions in behaviour of the system according to the ARV drug inventory model problem. In some literatures, either in system dynamics domain or not, have been explained about a case of HIV/AIDS, but it seems to be none has taken the case in Asian government pilot project, especially in Indonesia. So it seems to be one of a great reason why this paper could give a significant managerial impact if this methodology is implemented in real world. The statement comes from some HIV/AIDS literatures that have been studied, such as a mathematical model to describe the dynamic transmission of HIV/AIDS and suggests the use of counseling and treatment as main factors for controlling HIV infection (Kimbir and Oduwale, 2008); describing some literatures review on modeling dynamic systems of HIV/AIDS (Focus, 2008), such as: a dynamic model that uses a model of HIV transmission and its development into AIDS Anderson, 1988; Anderson and May, 1988; May, 1988) and a model of the spread of AIDS in the homosexual population of England (Dangerfield and Roberts, 1990); a method other dynamic systems of the epidemiology of HIV/AIDS that is designed to simulate the effects of triple combination ART in the treatment of HIV/AIDS (Dangerfield et al., 2001); system model to determine the relationship between HIV infection, risk groups, economic prosperity and the potential impact caused by increase in ART coverage (Jennifer, 2008); the use of a dynamic system in analyzing the policy when people with HIV/AIDS can receive ARV treatment and when to replace it with another drug regimen on the condition of minimal inventories (Robert, et al., 2009); the phenomenon of deliberate transmission of HIV infection with the system dynamic (Pedamallu, 2009).
In this paper, four indicators for evaluating the logistic system have been set up in CLD that contains two main model, such as inventory model and epidemic model. They are timeliness, accuracy, inventory management and delivery. Mainly the methodology consists of six stages +, such as model formulation, simulating the model, model validation, policy analysis and scenario development and policy implementation. The “+” is about the robustness of this model, a number of specific tests in step 3 that will be done on the model so that it will improve user confidence in the ability (Sterman, 1981). Here is the explanation of each step in the methodology.

**Step 1. Model Formulation**

In this step, the main CLD is developed. Conceptually, it starts by building the HIV/AIDS epidemic model, then ARV demand model and ended by inventory model. The Susceptible-Infected-Recovered (SIR) is used to promote a general epidemic model (Kermack and McKendrick, 1927; Sterman, 2000). The characteristics of HIV/AIDS in case location is also synthesize into a descriptive characteristic, e.g. up to December 2009, the accumulated data of AIDS patients recorded in East Java province reached 3234 men and 8373 HIV persons; and the transmission of HIV/AIDS also observed. It happens because by looking trends of HIV transmission based on risk factors in East Java Province showed that transmission occurred at the group homosexual, heterosexual, whispered, prenatal, blood transfusion and needle sharing. In the end of this step, CLD will be transform into the stock and flow diagram in the Powersims 2005 software to promote the continuous simulation.

**THE INVENTORY MODEL**

Population of HIV/AIDS that need ARV is input for inventory model. Patients who have used drugs should come once every month to control their health and given antiretroviral drugs. Enlargement and reduction of the number of patients affected by the number of patient, who died, stop or failed to follow-up and also increase ARV coverage. This inventory model design consists of three variables namely inventory stock in the hospital, inventory in the provincial warehouse and central warehouse, see figure 1. Structure inventory in the central and province warehouse will change periodically and the structure of inventory at the hospital experienced changes in each period due to drug dispensing to patients and receiving drug from provincial warehouse. The key point of each inventory is to reach the service level in the hospital constant at 100%, since the characteristics of ARV treatment that requires continuous treatment and no stock outs.

**THE EPIDEMIC MODEL**

The model of epidemic is divided into eight sub model, such as:

*Model 1* is the representation of SI (Susceptible Infected), see figure 2.
*Model 2* is developed by adding model 1 with AIDS population in the model structure, see figure 3. In this model, the incubation period is assumed to be 8 years (Gray et al., 2001; Grosslurth et al., 1995; and Quinn et al., 2000).
*Model 3* is developed by adding the number of people who died from AIDS in the model 2 structure, see figure 4. The average length of AIDS people life without ART is less than one year. In this model, the average time living with AIDS to death if no treatment is only one year or less (UNAIDS / WHO, 2007; Gray et al., 2001).
*Model 4* is developed by inputting factors of birth and death not caused by AIDS in structure model 3, see figure 5.
*Model 5* is the development of model 4. Children are not treated will die prematurely before their first birthday (Gerobak-Spira et al., 2000).
*Model 6* is developing from model 5 with risk factors inserting needles transmission by use of syringes that are not sterile.
*Model 7* is the development of model 6 by considering that among the HIV population, there are people dying before entering into the AIDS population.
*Model 8* is developed by incorporating the effect of ARV treatment in sub model HIV Children, sub model sharing needle and model 7, see figure 6.

The next step after finishing the model of an epidemic of HIV/AIDS is the ARV Demand Model for patients with HIV / AIDS based on data from monthly reports in four hospitals pilot project, see figure 7.

**Step 2. Simulating The Model**
Term in this modeling simulation was set for 37 years (1989-2025) because the dimensions of time should be extended to the past to show how the problem appeared and explained the phenomenon (Sterman, 2000) and enough to capture the indirect effects and potential delays of the policy made by (Ford, 1999).

Step 3. Model Validation
It starts by model verification. It’s needed to determine whether the model has been coded correctly and consistently. Therefore it could ensure that the simulation model is running as desired (House and McLeod, 1997; Greenberger et al., 1976). Then the validation is done by doing a statistical hypothesis testing. The series of testing are also done to improve user confidence, such as model testing encoding, numerical method dependent error, direct extreme condition, adequacy boundary, test confirmation and empirical parameter structure, and the end is face validity test (Ford, 1999).

Step 4. Policy Analysis
By extending the simulation until the year 2025 as the planning of future policy decision making for both HIV-AIDS prevention program planning and inventory policy of decentralization of ARV drug, then the policy program for HIV/AIDS could be improved.

Step 5. Scenario Development
In this step, several scenarios that maybe happen in the future are inputted to the simulation then it could give a good advice to create a simultaneous policies.

Step 6. Policy Implementation
The advice of optimal solution reaches the 100% service level and also it reaches a low cost of ARV drug inventory. The policy maker then implements it through a policy.

RESULTS AND DISCUSSION
After doing each step in methodology, the sensitivity analysis is employed since it is important to get the behaviour of the system. There are three models of sensitivity analysis are conducted (Richardson and Pugh, 1981), such as sensitivity of numerically (see figure 8), conduct sensitivity (see figure 9) and sensitivity policy (see figure 10). By analyzing figure 8 to 10, it shows that inventory design policy has a great impact in maintaining service level in the hospital, while optimizing the inventory cost of ARV drug.

MANAGERIAL IMPLICATIONS
The managerial implications of this proposed methodology are the policy maker can use for projection HIV/AIDS population in the future and the creation of budget planning of ARV drug both by government and donors. Therefore, the efficiency in eliminating waste in inventory cost while producing a high service level in ARV drug in hospital could produce a decreasing number of suffered or died people because of the stock out of ARV drug.
FIGURE 1
STOCK AND FLOW DIAGRAM FOR INVENTORY MODEL
FIGURE 2
SUB MODEL 1 STOCK AND FLOW DIAGRAM FOR EPIDEMIC MODEL

FIGURE 3
SUB MODEL 2 STOCK AND FLOW DIAGRAM FOR EPIDEMIC MODEL
FIGURE 6
COMPARISON TOTAL POPULATION OF HIV/AIDS MODEL 8 WITH REFERENCE MODE

FIGURE 7
SUB MODEL 6 STOCK AND FLOW DIAGRAM FOR ARV DEMAND
FIGURE 8
SENSITIVITY POLICY SERVICE LEVEL DUE TO CHANGES REPLENISHMENT PERIOD

FIGURE 9
THE IMPACT OF POLICY IN HIV/AIDS PREVENTION ON THE POPULATION OF HIV/AIDS

FIGURE 10
SERVICE LEVEL IN THE HOSPITAL WITH CHANGES IN INVENTORY BUFFER POLICY
CONCLUSION

The proposed inventory model shows that the inventory policy in the hospital should keep inventory for 2.5 months, the provincial warehouse for 4 months and the central warehouse for 15 months. It will generate 100% service level in hospitals leads to minimizing inventory cost.

The limitation of this paper includes four factors: 1) sexual risk factors, sharing needles, and HIV from pregnant mother to child 2) factors affecting the population model are limited in the number of births and deaths of the population 3) the scope of study area is only in East Java province 4) the ARV drug procurement system only comes from the state budget funds.

The future research includes two areas: 1) a developing epidemic HIV/AIDS model for more specific objects such as high-risk group (e.g. sex workers, etc.) 2) creating specific sub model for people sharing needles in epidemic of HIV/AIDS model.

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