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Prediction of Availability of Packed Red Cells (PRC) at PMI Surabaya City Using Ensemble Kalman Filter as Management of Blood Transfusion Management

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Abstract. Blood transfusion in terms of both quality and quantity is needed by patients with various health problems they experience. Along with the increased need for blood transfusion, the management of blood transfusion arrangements (blood collection from donors, selection, distribution, storage), and the ability of nurses to provide transfusion to patients is needed. If there are a lot of mistakes in both the ability of management and the ability of nurses, it can not only lead to a fatal impact on a patientbut also increase amount of need for blood transfusion. Due to the importance of blood transfusion, maintaining the stability of blood stock must be done so as not to cause blood loss due to exces of the blood stock. To minimize such loss, blood prediction is needed. The objective of this study is to predict blood demand for blood type of Packed Red Cells (PRC) or concentrated red blood cells at PMI Surabaya by using the method of Ensemble Kalman Filter (EnKF) and Ensemble Kalman Filter Square Root (EnKF-SR). The simulation results show that both methods have high accuracy with an error of less than 1% and RMSE of EnKF-SR .The best simulation exhibited the error between the real data and the simulation with EnKF-SR was in the order of 0.0023574, whereas with EnKF was some 0.025566 with generated 400 ensembles.

1.   Introduction

In Blood transfusion in terms of both quality and quantity is needed by patients with various health problems. As need for blood transfusion increases,improved ability in management of transfusion blood (covering blood collection from donors, selection, distribution, and storage) is required and so does the ability of nurses to provide transfusions for patients. When mistakes frequently occur both in the management and in the performance of the nurses, it will cause a fatal impact on the patient himself and eventually increase the amount of blood needed for blood transfusion [1]. The kinds of mistakes frequently made are sampling for examinations, wrong labeling, technical mistakes or those due to the nurses' lack of understanding of selecting blood components in accordance with specifications. Mistakes also frequently occur in busy situations, during which the number of nurses is less than the number of clients. Intensified by the work situation or the condition of under pressure, theattention of nurses to check the blood in detail before transfusion becomes less focused. Errorstake placeunintentionally can reduce the safety of the client undergoing the transfusion process so that more possible side effects of reactions rising from transfusions will be encountered with and experienced by the client [2].

To minimize errors, it is necessary to predict or estimate the number of blood requests at the Indonesian Red Cross (PMI). In this paper, the prediction of PRC blood demand is limited only to PMI Surabaya City. Estimates are made because a problem can sometimes be solved using presvious information or data related to the problem. One estimation method is the Ensemble Kalman Filter (EnKF) which functions to minimize covariance error estimation by generating a number of ensembles [3]. The development of the EnKF method is the Kalman Filter Square Root Ensemble (EnKF-SR) which is obtained by adding the square root factor at the EnKF correction stage [4]. In this paper, the EnKF and EnKF method was applied to predict the demand for PRC blood as a material for consideration of blood transfusion management at PMI Surabaya City.

2.   Ensemble Kalman Filter (EnKF)

The algorithm Ensemble Kalman Filter (EnKF)can be seen [5,6]:

1.   Model system and measurement model

$$x_{k+1} = f(x_k, u_k) + w_k \tag{1}$$
$$z_k = H x_k + v_k \tag{2}$$
$$w_k \sim N(0, Q_k), \ v_k \sim N(0, R_k) \tag{3}$$

2.   Initialization

Generate N *ensemble* as the first guess $\bar{x}_0$

$$x_{0,i} = [x_{0,1} \quad x_{0,2} \quad \dots \quad x_{0,N}] \tag{4}$$

The first value: $\hat{x}_0 = \frac{1}{N}\sum_{i=1}^{N} x_{0,i} \tag{5}$

3.   Time Update

$$\hat{x}_{k,i}^- = f(\hat{x}_{k,-1,i}, u_{k-1,i}) + w_{k,i} \text{where} w_{k,i} = N(0, Q_k) \tag{6}$$

Estimation : $\hat{x}_k^- = \frac{1}{N}\sum_{i=1}^{N} \hat{x}_{k,i}^- \tag{7}$

Error *covariance*:

$$P_k^- = \frac{1}{N-1}\sum_{i=1}^{N}(\hat{x}_{k,i}^- - \hat{x}_k^-)(\hat{x}_{k,i}^- - \hat{x}_k^-)^T \tag{8}$$

4.   Measurement Update

$$z_{k,i} = H x_{k,i} + v_{k,i} \qquad \text{where} v_{k,i} \sim N(0, R_k) \tag{9}$$

Kalman gain : $K_k = P_k^- H^T (H P_k^- H^T + R_k)^{-1} \tag{10}$

Estimation : $\hat{x}_{k,i} = \hat{x}_{k,i}^- + K_k(z_{k,i} - H\hat{x}_{k,i}^-) \tag{11}$

$$\hat{x}_k = \frac{1}{N}\sum_{i=1}^{N} \hat{x}_{k,i} \tag{12}$$

Error covariance : $P_k = [I - K_k H] P_k^- \tag{13}$

3.   Ensemble Kalman Filter Square Root(EnKF-SR)

The algorithm Ensemble Kalman Filter Square Root (EnKF-SR) can be seen [7]:

1.   Model system and measurement model

$$x_{k+1} = f(x_k, u_k) + w_k \tag{14}$$

$$z_k = H x_k + v_k \tag{15}$$

$$w_k \sim N(0, Q_k), \ v_k \sim N(0, R_k) \tag{16}$$

2.   Initialization

Generate N *ensemble* as the first guess $\bar{x}_0$

$$x_{0,i} = [x_{0,1} \quad x_{0,2} \quad \dots \quad x_{0,N}] \tag{17}$$

The first Mean *Ensemble* :

$$\bar{x}_{0,i} = x_{0,i} 1_N \tag{18}$$

The first *Ensemble* error:

$$\tilde{x}_{0,i} = x_{0,i} - \bar{x}_{0,i} = x_{k,i}(I - 1_N) \tag{19}$$

3.   Time Update

$$\hat{x}_{k,i}^- = f(\hat{x}_{k,-1,i}, u_{k-1,i}) + w_{k,i} \tag{20}$$

where $w_{k,i} = N(0, Q_k)$

Mean *Ensemble* : $\bar{x}_{k,i}^- = \hat{x}_{k,i}^- 1_N \tag{21}$

Error *Ensemble* :

$$\tilde{x}_{k,i}^- = \hat{x}_{k,i}^- - \bar{x}_{k,i}^- = \hat{x}_{k,i}^-(I - 1_N) \tag{22}$$

4. Measurement Update

$$z_{k,i} = Hx_{k,i} + v_{k,i} \tag{23}$$

where $v_{k,i} \sim N(0, R_k)$

$S_k = H\tilde{x}_{k,i}^-$, $E_k = (v_1, v_2, \dots, V_N)$ and

$$C_k = S_k S_k^T + E_k E_k^T \tag{24}$$

Mean Ensemble :

$$\bar{x}_{k,i} = \bar{x}_{k,i}^- + \tilde{x}_{k,i}^- S_k^T C_k^- (\bar{z}_{k,i} - H\bar{x}_{k,i}^-) \tag{25}$$

Square Root Scheme:

- eigenvalue decompotition from

$$C_k = U_k \Lambda_k U_k^T \tag{26}$$

- determine matrix $M_k = \Lambda_k^{\frac{1}{2}} U_k^T S_k^-$ $\tag{27}$

- determine SVD from $M_k = Y_k L_k V_k^T$ $\tag{28}$

Ensemble Error :

$$\tilde{x}_{k,i} = \tilde{x}_{k,i}^- V_k (I - L_k L_k^T)^{\frac{1}{2}} \tag{29}$$

Ensemble Estimation   :

$$\hat{x}_{k,i} = \tilde{x}_{k,i} + \bar{x}_{k,i} \tag{30}$$

To evaluate of estimation result accuracy byEnKF and EnKF-SR algoritm, can be seenby calculating Root Mean Square Error (RMSE) [7].

$$\text{RMSE} = \sqrt{\frac{\sum_i^n \left(X_{obs,i}(k) - X_{model,i}(k) \right)^2}{n}} \tag{31}$$

With

$X_{obs,i}(k)$ = observation data

$X_{model,i}(k)$ = model data

n = iteration

4. **Computational Result**

This simulation was carried out on PRC blood type data at PMI Surabaya city as follows:

Table 1. Blood Data of PRC type

Data of PRC type on 2013-2017											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Des**
2013	4324	4428	4640	3973	4420	4430	4246	4993	4600	4291	4478	4712
2014	4983	4431	4951	4190	4466	4229	4614	5050	4103	4392	4402	4469
2015	5391	4296	4418	4212	4144	3762	3992	4274	4229	4353	4061	4351
2016	4521	3886	3878	3925	3981	3698	3870	3851	3774	4023	3785	3763
2017	3945	3499	3602	3526	3759	3535	4601	4090	3679	3814	3615	3599

From the blood data of PRC type in Table 1, a mathematical function was obtained for the blood supply of PRCtypes using Mathematica software. The Mathematica software simulation resultedin a function as follows:

$f(x) = 4542.33 - 1.64595x - 0.244018 x^2$

$f'(x) = -1.64595 - 0.488036 x$ $\tag{32}$

Because the system requires discretation, the PRC blood stock function model in equation (25) are discreted using the finite difference method.

The change of state variables in respect to the time is approximated by forward scheme of finite difference. Then we get the following.

$f' = \frac{df}{dt} \approx \frac{f_{k+1} - f_k}{\Delta t}$ $\tag{33}$

from equations (32) and (33), the modified PRC blood stock function model in (32) is obtained as follows:$f_{k+1} = (1.64595 - 0.488036\ x_k)\Delta$ (34)

After the function was obtained, then it was simulated with the Matlab software. In this paper a simulation was carried out by applying the EnKF and EnKF-SR algorithm to the function of blood stock of PRC type. The simulation results were evaluated by comparing the real conditions in the field with the estimation results of EnKF and EnKF-SR. This simulation used $\Delta t = 0,1$ and 100 iterations and generated 100, 200, 300 and 400 ensembles. Figure 1 is a comparison of the estimation results by the EnKF and EnKF-SR methods by generating 100 ensembles.Figure 2 is the simulation result of the EnKF and EnKF-SR methods by generating 200 ensembles. Figure 3 is a simulation of the EnKF and EnKF-SR methods by generating 300 ensembles.Figure 4 is a simulation of the EnKF and EnKF-SR methods by generating 400 ensembles.
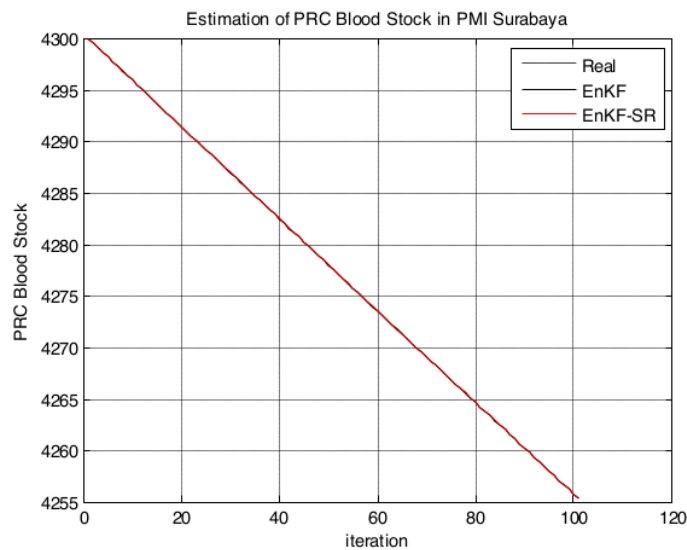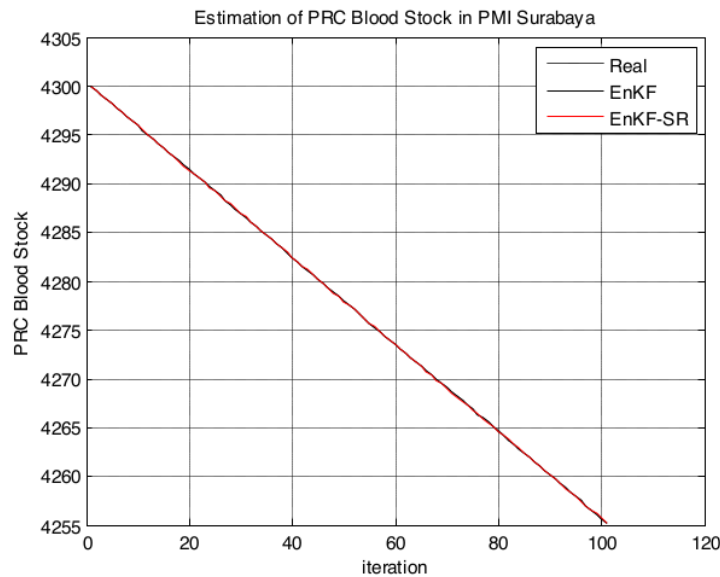

Figure 1. Estimation of PRC blood stock by EnKF and EnKF-SR methods with 100 ensembles
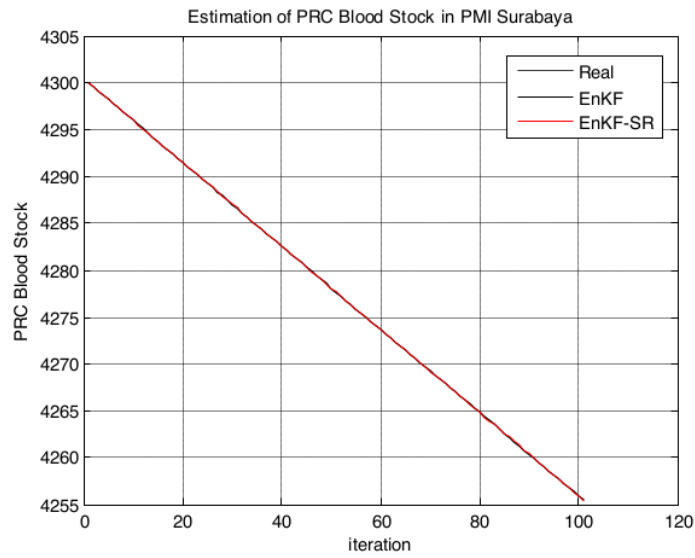
Figure 2. Estimation of PRC blood stock by EnKF and EnKF-SR methods with 200 ensembles
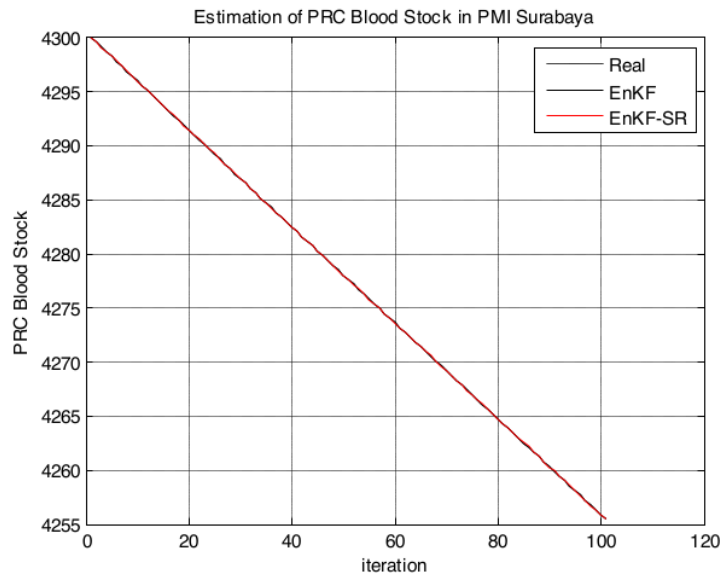
Figure 3. Estimates of PRC blood stock by EnKF and EnKF-SR methods with 300 ensembles

Figure 4. Estimates of PRC blood stock by EnKF and EnKF-SR methods with 400 ensembles

Figures 1 -4 show that the estimation results of PRC blood stock have very high accuracy with errors of less than 1% as we can see in the real graphs. The accuracy of the EnKF and EnKF-SR methodsshowed no significant difference. In Figure 1 and Table 2, it appears that the EnKF-SR method with RMSE of 0.0030719 has higher accuracy than that of the EnKF with RMSE of 0.02099, but the difference is not much. Likewise, in Figures 2 and 3 with generated 200 and 300 ensembles, it can be said that the EnKF-SR method has higher accuracy than the EnKF, whereas the EnKF-SR method has a smaller RMSE value.in Figures 4 with generated 400 ensembles, it can be said that the EnKF-SR method has higher accuracy than the EnKF with error of EnKF-SR 0.0023574 and error of EnKF 0.025566, whereas the EnKF-SR method has a smaller RMSE In conclusion, both methods can be used as a method for predicting or estimating either PRC blood stock or other blood types.

Table 2. Comparison of theRMSE values by the EnKF and EnKF-SR based ongenerated 100, 200,and 400 Ensembles

	100 ensembles		200 ensembles		300 ensembles		400 ensembles	
	EnKF	**EnKF-SR**	**EnKF**	**EnKF-SR**	**EnKF**	**EnKF-SR**	**EnKF**	**EnKF-SR**
RMSE	0.02899	**0.0030719**	0.027554	**0.0033243**	0.026562	**0.0029786**	0.025566	**0.0023574**
Simulation Time	3.289 s	5.1948 s	6.865 s	7.359 s	8.761 s	9.826 s	10.232 s	11.154 s

In Table 2, it appears that the EnKF-SR method has higher accuracy than the EnKF. even though the simulation time took longer timedue to the square root factor in the correction stage, making it more accurate in estimating. If compared to the number of ensembles, then 400 ensembles resulted in higher accuracy either by the EnKF method or the EnKF-SR, due to the effect ofthe generation of more ensembleson the level of the accuracy of the simulation.In general as seen in the Table 2, the results of the four simulations were highly accurate. The firstsimulation by generate 100 ensemble with error of 0,030719 or accuracy of 99,5%, the second simulation by generate 200 ensemble with error of 0,0033243 or accuracy of 99,3%. The third simulation by generate 300 ensemble with error of 0,0029786 or accuracy of 99,6%, and %. The fourthsimulation by generate 300 ensemble with error of 0,023574 or accuracy of 99,5%. In general, the methods of EnKF and EnKF-SR can be used as a method to estimate or predict PRC blood stock with excellent accuracy. Based on the simulation results above, it is likely that both methods can also be used to estimate othertype of blood stock, so it

can support the work of PMI Surabaya's blood transfusion management in particular and PMI in all cities in Indonesia.

5. Conclusion

Based on the results of the simulation analysis, EnKF and EnKF-SR method can be used as a method to estimate or predict PRC blood stock with excellent accuracy and errors of less than 1%, but the EnKF-SR method has higher accuracy than the EnKF. Based on the simulation results above, it is likely that both methods can also be used to estimate othertype of blood stock, so it can support the work of PMI Surabaya's blood transfusion management in particular and PMI in all cities in Indonesia.

Open problem. How to implemented Ensemble Kalman Filter (EnKF) and Ensemble Kalman Filter Square Root (EnKF-SR) for estimation of othertype of blood stock in all cities in Indonesia.

Acknowledgement

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