

## **Understanding the dynamics of the blood supply chain: is prediction possible?**

Wilding R.\*, Hick R.\*\*, Chapman J. F.\*\*

\*Cranfield School of Management, \*\*Blood Stocks Management Scheme

Since the late 1950's it has been recognised that systems used internally within supply chains can cause oscillations in demand and inventory as requirements pass through the system. The uncertainty generated by these oscillations can result in shortages and excesses and an increased reliance on inventory to buffer these effects. Greater understanding of the generation of uncertainty within the supply chain can result in improved management.

One aspect of uncertainty in the blood supply chain is the demand system and the possibility for generation of deterministic chaos. A MS-DOS based computer program was developed that was able to detect and quantify the extent of this uncertainty using Lyapunov exponents. Lyapunov exponents can be used to identify whether or not a system is chaotic. Negative exponents indicate a stable system; a zero exponent indicates a fixed point system; and positive exponents indicate a chaotic system. The magnitude of the Lyapunov exponent gives a reflection of the time scale over which the dynamics of the system are predictable; so the exponent can be used to approximate the average prediction horizon (APH) of a system. After this APH has been reached, the future dynamics of the system cannot be forecast with any accuracy. This occurs because any cause and effect relationship between current and future data becomes increasingly blurred and is eventually lost.

The demand system was investigated by considering total red cell demand between 01-Jan-2000 and 08-Sept-2005 using data from the Blood Stocks Management Scheme. The data analysed consisted of 2,073 consecutive day's demand, had a median of 7,401 and a range of 10,440. Analysis of the data revealed a positive Lyapunov exponent (0.282), which indicated a chaotic system. A test confirmed that the data was not random, indicating that there was a degree of correlation between successive days demand. A further test confirmed that there was no significant mean level shift over time that might explain the chaotic behaviour.

The APH is linked to the degree of accuracy with which the demand can be specified. The base unit for the demand data was  $1/0.282 = 3.5$  days. As an example, if demand can be specified to an accuracy of 1 in 1000 (10 bit accuracy), the APH would be  $10 \times 3.5 = 35$  days. The analysis confirms the lay assumption that total red cell demand is chaotic and as such cannot be predicted infinitely into the future. The analysis of APH reveals an intriguing relationship between predictability of demand and the shelflife of the product (35 days). In the case of demand, the 'degree of accuracy' can be thought of as the amount of unplanned, emergency demand occurring. Thus if emergency demand was 1% of total demand, the accuracy would be 1 in 100 (7 bit accuracy), which gives an APH of  $7 \times 3.5 = 25$  days.

The analysis confirms the Lyapunov exponent technique as a useful tool that could be applied to other demand streams, e.g. group/hospital specific, to establish the uncertainty within these systems.