An Analytical Study of Bullwhip Effect in Supply Chain Management

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ABSTRACT

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request or demand. The supply chain not only includes the manufacturers and suppliers, but also transporters, warehouses, retailers, and finally the end consumers themselves. The objective of every supply chain is to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request. An important phenomenon in Supply Chain Management is known as bullwhip effect (BWE), which suggests that the demand variability increases as one moves up a supply chain. Bullwhip effect is an undesirable phenomenon in the supply chain which exacerbates the supply chain performance. The impact of BWE is to increase manufacturing cost, inventory cost, replenishment lead time, transportation cost, labor cost for shipping and receiving, cost for building surplus capacity and holding surplus inventories, and to decrease level of product availability and relationship across the supply chain. Various factors can cause bullwhip effect, one of which is customer demand forecasting. In this study, impact of forecasting methods on the bullwhip effect and mean square error has been considered. The preceding study highlights the effect of forecasting technique, order processing cost and demand pattern on BWE and mean square error (MSE). The BWE and MSE have been evaluated using MATLAB coding. The results were analyzed using ANOVA and Fuzzy Logic, and finally the optimal parameters for minimum values of BWE and MSE have been determined.

Keywords: Bullwhip effect; supply chain management; automotive component manufacturers; original equipment manufacturers; automotive industry.

INTRODUCTION

Supply chain management (SCM) is a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses and stores so that merchandise is produced and distributed at the right quantities, to the right location and at the right time in order to minimize system wide cost while satisfying service level requirement. It can also be defined as the coordination of production, inventory, location and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served. Supply chain management arose in late 1980s and came into widespread use in 1990s. Earlier it was known as "Logistics" and "Operations Management". There is a difference between the concept of supply chain management and traditional concept of logistic:- Logistics refers to activities that occur within the boundaries of a single organization whereas supply chain management refers to network of companies that work together and coordinate their action to deliver a product to market. Logistics focuses its attention on activities such as procurement, distribution, maintenance and inventory management whereas supply chain management acknowledges all the traditional logistics, and also include activities such as marketing, new product development, finance and customer service. Effective supply chain management requires simultaneous improvement in both customer service level and the internal operating efficiencies of the companies in the supply chain. Customer service at its most basic level means consistently high order fill rates, high on-time delivery rates and very low rate of products returned by customers. Internal efficiency in an organization of a supply chain means that these organizations get an attractive rate of return on their investments in inventory and other assets, and also find ways to lower their operating and sales expenses.

A TYPICAL SUPPLY CHAIN INCLUDES THE FOLLOWING STAGES:

1. Customer
2. Retailer
3. Wholesaler/distributor
4. Manufacturer
5. Component/raw material supplier

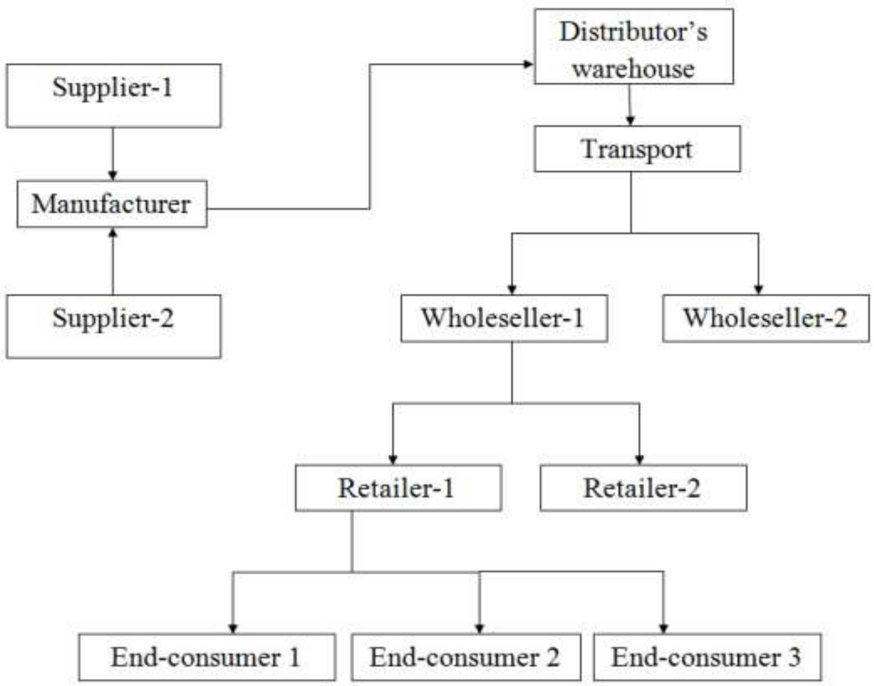

Figure 1: Basic Layout of Supply Chain

LITERATURE STUDY

Supply chains consist of vertical structures (stages) with many different owners. In the automotive industry, the supply chain structure consists of original equipment manufacturers (OEMs), original equipment suppliers (OESs), automotive component manufacturers (ACMs) and the automotive retail and aftermarket (Naude 2009:30). For example Ford Motor Company has thousands of suppliers from Goodyear to Motorola; each of these suppliers has many suppliers in turn. Information is distorted as it moves across the supply chain because complete information is not shared between stages. This distortion is aggravated by the fact that supply chains today produce a large amount of product variability. For example, Ford produces many different models with several options for each model. The increased variety makes it difficult for Ford to coordinate information exchange with thousands of suppliers and dealers.

The fundamental challenge nowadays is for supply chains to achieve coordination in spite of multiple ownership and increased product variety. (Chopra & Meindl 2007:497-498). The bullwhip effect is caused by a lack of coordination between organisations and their suppliers (Ravichandran 2008:88). A supply chain lacks coordination if each manufacturer in the chain observes it own objective, without taking into account the impact on the entire chain (Chopra & Meindl 2007:49). Therefore, synchronous supply cannot be achieved without high levels of coordination across the supply network. A lack of coordination across the supply network will result in the bullwhip effect (Christopher 2005:199). The bullwhip effect is also known as the 'Forester Effect' after Jay Forester, who identified that small disturbances in one part of the supply chain can very quickly become magnified as the effects spread through the pipeline (Christopher 2005:196). The limits and contents of each Supply Chain's nonlinear relation network are not same for every Manufacturing or Service Company. For this reason, before modeling a Supply Chain, the first step that a model builder should do is defining the scope of Supply Chain model. As Min and Zhou (2002) states there is no systematic way of defining the scope of Supply Chain problem. But there are different guidelines in the literature.

One of them is proposed by Stevens (1989). This guideline is consisting of three levels of decision hierarchy. First one is competitive strategy which includes location-allocation decisions, demand planning, distribution channel planning, strategic alliances, new product development, outsourcing, supplier selection, information technology selection, pricing, and network restructuring. Secondly tactical plans; includes inventory control, production/distribution coordination, order/freight consolidation, material handling, equipment selection, and layout design. Finally operational routines; that includes vehicle routing/scheduling, workforce scheduling, record keeping, and packaging Another guideline to follow is suggested by Cooper et al. (1997b). The three structures of a Supply Chain network suggested is: (1) the type of a Supply Chain partnership which can be primary and secondary; (2) the structural dimensions of a Supply Chain network that can be horizontal and vertical; (3) the characteristics of process links among Supply Chain partners such as managed business process links (firm integrates a Supply Chain process with one or more customers/suppliers), monitored business process links (firm is involved in monitoring or auditing how the link is integrated and

THE BULLWHIP EFFECT

Even a slight change in consumer sales ripples backwards in the form of magnified oscillations upstream, resembling the result of a flick of a bullwhip handle. Because the supply patterns do not match the demand patterns, inventory accumulates at various stages and shortages and delays occur at others. Swink, Melnyk, Cooper and Hartley (2011:225-226) describe the bullwhip effect as "a small disturbance in the flow of orders generated by customers that produces successively larger disturbances at each upstream stage in the supply chain". Small variations in demand at the customer end of the supply chain can therefore produce massive variations in orders upstream. Burt, Petcavage and Pinkerton (2010:532) view the bullwhip effect as "… a problem of fictional demand or phantom demand". Fawcett et al. (2007: 515) define the bullwhip effect as 'exaggerations of fluctuating demand' through the supply chain as suppliers overcompensate to avoid stock outages, and then under-anticipate future demand. The observed variability in the customer demand increases the further the supplier is from the customer (Webster 2008:85). For example demand variation will increase from retailers to wholesalers, manufacturers and their suppliers (Dooley, Yan & Gopalakrishnan 2010:13). The bullwhip effect is therefore more severe in larger supply chains with more suppliers and customers (Wisner, Tan & Leong 2008:10).

The lack of supply chain coordination leads to a phenomenon known as bullwhip effect (BWE), in which fluctuation increases as we move up the supply chain from retailers to wholesalers to manufacturers to suppliers. The bullwhip effect distorts demand information within the supply chain, with each stage having a different estimate of what demand looks like. Common practical effects of this variance amplification were found in cases of companies Procter & Gamble (dealing with mainly diapers) and Hewlett-Packard (dealing with mainly computers and its components), and are presented to students worldwide through the business game "Beer Game" developed at MIT. Since then, worldwide researches have been carried out by various authors to study different aspects of SCM causing the bullwhip effect and suggested a number of methods to reduce its effect.

The initial work on the bullwhip effect was carried out by Jay W. Forrester . In his groundbreaking work he discovered existence of demand amplification or bullwhip effect while working on a four echelon supply chain. He predicted decision making process and time delay in each phase of Supply Chain Network (SCN) and the factory capabilities could be the main reason of the demand amplification. He also found that the advertising factor also influences the system by generating BWE. Burbidge studied about production and inventory control along with demand amplification. He concluded that if demands are carried over a series of inventories using "stock control ordering" then an increase in demand variability would occur with every transfer of demand information. Sterman in his works focused on the existence and causes of BWE using an experimental four-stage SCN role-playing simulation which simulated the beer distribution in a simple SCN. This SCN simulation game successfully portrays the idea of system dynamics. The "Beer Distribution Game", is widely used for teaching the behavior, concept and structure of SCN. He also analyzed the decision methodology of the participants of the SCN and found out that the participants are not focusing on the system delays and nonlinearities. He concluded that anchoring and adjustment heuristics are inconsequent as these heuristics lack sensibility to delay. Towill and Wikner et al. used Forrester's model with additional quantitative measures, and analyzed the supply chain system applying the system dynamics model. To will defined System Dynamics as "A methodology for modeling a redesign of manufacturing, business and similar systems which are partly man and partly machine". He concluded that time delay is one of the reasons behind demand amplification.

METHODOLOGY

Supply Chain can be modeled with stochastic, hybrid, information technology (it)-driven or simulation modeling approaches. The type of modeling method should be chosen according to the defined problem and Supply Chain structure. In this study, impact of Supply Chain strategies on Bullwhip Effect is examined. In addition to this, all different Supply Chain strategies effect on other performance measures such as net stock amplification and the total cost are mentioned as another discussion topic of this study. The Supply Chain model should be capable enough to show the consequences of any increase or decrease of factors to performance measures. For this reason, most suitable modeling tool for this type of Supply Chain study is chosen as 'simulation'. Details for simulation method and sample Supply Chain simulation studies are given to better explain the other reasons for selection of the simulation method. Y. Chang et al. (2001) states that Supply Chain simulation "helps to understand the overall Supply Chain processes and characteristics by graphics/animation.

Supply Chain simulation is able to capture system dynamics: using probability distribution, user can model unexpected events in certain areas and understand the impact of these events on the Supply Chain. It could dramatically minimize the risk of changes in planning process: By what-if simulation, user can test various alternatives before changing plan". In addition to these explanations, Enns (2003) defined the procedure for the Supply Chain modeling in six steps. The first step is to understand the system, then to design the scenario and data collection. Next target should be defined for each performance measure and the definition of termination condition. Finally the Supply Chain strategies should be evaluated.

The simulation tools are not limited by available software packages, some researchers generate their own simulation tools, for example; S.T. Enns et al. (2003) made a simulation test bed for production and Supply Chain modeling and J. Liu et al. (2004) demonstrated another Supply Chain simulation tool which is called easy-supply chain, and it can be used for different Supply Chain studies. Harrell and Tumay (1994) classified simulation in two categories. First one is "methods for solution and evaluation". In this category what-if scenarios are tested by using spreadsheet, discrete event system or system dynamic simulations. Second category is "method for solution generation" which aims to find the best solution for a given objective. Classical optimization approaches such as linear and non-linear optimization and simulation optimizations are the examples for this category. This thesis aim is to both solution evaluation and solution generation. As a solution evaluation, spreadsheet simulation is chosen for simulation tool to test different Supply Chain strategies. And for solution generation several factors are considered with two different levels each and the design of experiment is made to find best possible solution scenarios.

DEMAND FORECASTING IN A SUPPLY CHAIN

Forecasting of future demand is essential for taking decisions related to supply chain. Demand forecasting is the activity of estimating the quantity of a product or service that consumers will purchase in future. It involves techniques including both informal and quantitative methods. Informal methods include educated guess, prediction, intuition etc whereas quantitative methods are based on the use of past sales data or current data from test markets. It may be used in making pricing decisions, in assessing future capacity requirements, or in making decisions on whether to enter a new market not.

ANALYSIS OF VARIANCE

Minitab R14 software was used for experimental analysis. The process parameters that significantly affect the performance characteristic were identified using a statistical analysis of variance (ANOVA). ANOVA test can also be used for estimating the percentage contribution (%P) of various process parameters on the selected performance characteristic. In addition, significance of factors can also be determined by comparing calculated F-value with standard Fvalue at a particular level of confidence (95% in this study). Thus, information about the effect of each controlled parameter on the quality characteristic of interest can be obtained. Two performance measures- bullwhip effect and mean square error are considered with an aim to minimize all these simultaneously at the single factor setting. Fuzzy logic unit can combine the entire considered performance characteristic (objectives) into a single value that can be used as single characteristic in optimization problems. In the present study, to consider the two different responses in ANOVA method, the bullwhip effect values and mean square error values are normalized and then processed by fuzzy logic unit.

FUZZY LOGIC UNIT

The structure of the two-input-one-output fuzzy logic unit is shown in Figure 2. A fuzzy logic unit comprises of a fuzzifier, knowledge base (membership functions and fuzzy rule base), an inference engine, and a defuzzifier. These components are described below: Fuzzifier: It is used to apply real input to the fuzzy system. In fuzzy literature, this input is called crisp input since it contains precise information about the specific information about the parameter. It converts the precise quantity to the form of imprecise quantity like 'small', 'medium', 'large' etc. with a degree of membership to it. Typically, the value ranges from 0 to 1.

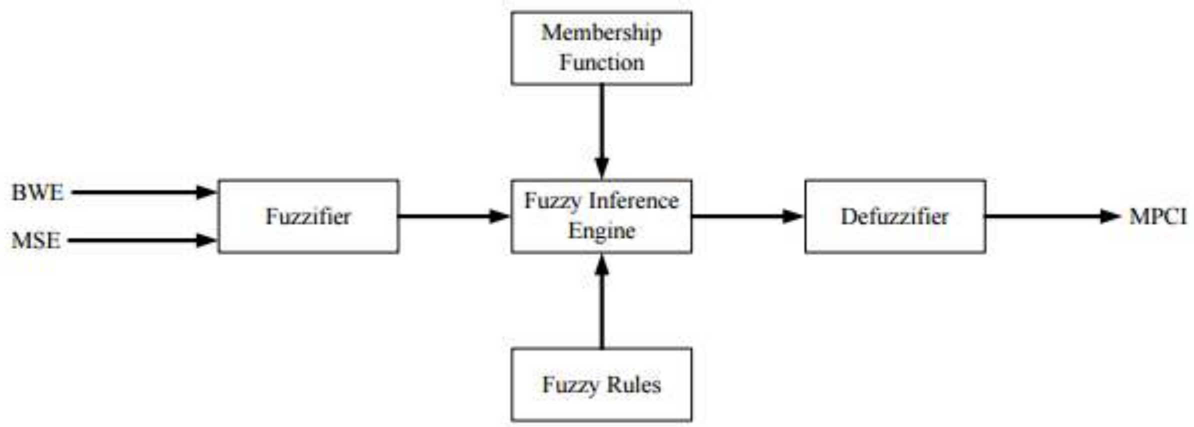

Figure 2: Structure of the two-input-one-output fuzzy logic unit

As shown in Figure 2 crisp inputs are BWE and MSE, and crisp output is MPCI. Knowledge base: It is the most important part of the fuzzy system. In this both rule base and database are jointly referred. Membership functions of the fuzzy sets used in fuzzy rules are defined by the database. Rule base contains a number of fuzzy if-then rules.

DEVELOPMENT OF MAMDANI FUZZY MODEL

In the analysis, fuzzy system (Mamdani model) is used to estimate the multi-performance characteristic index. The set of output data is evaluated through the given input condition in the model. The proposed Mamdani fuzzy model for evaluation of multi performance characteristic index is presented in Figure 3. The given model has a multiple input and single output

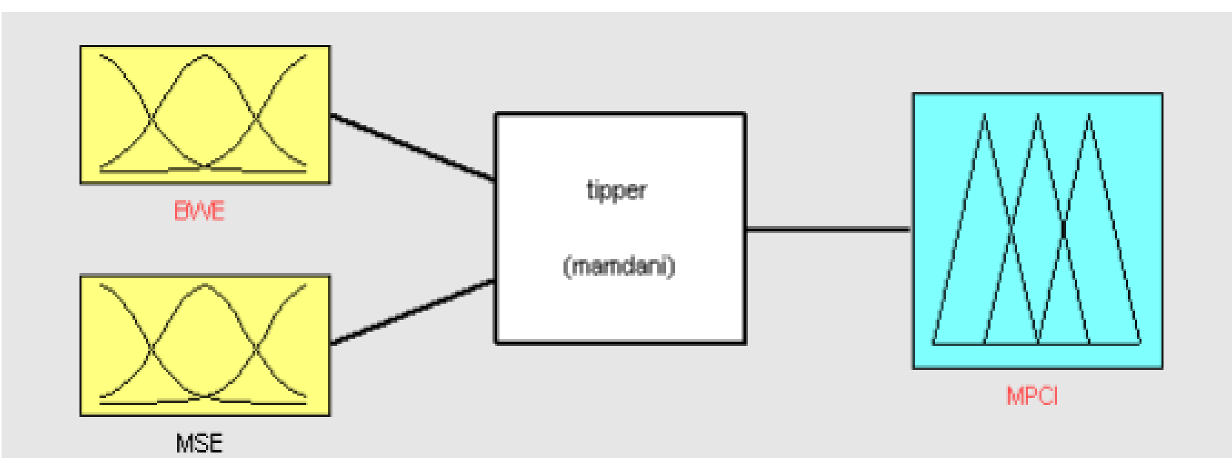

Figure 3: Structure of Mamdani fuzzy rule based system for evaluating Multi Performance Characteristic Index (MPCI)

EXPERIMENTAL DETAILS

Bullwhip effect is a wasteful phenomenon that occurs due to lack of information across the supply chain. This phenomenon is one of the current challenges that a supply chain faces. This makes it essential to understand the performance of supply chain on the basis of bullwhip effect and mean square error (MSE) with the variation of process parameters. In this study bullwhip effect and mean square error are considered as measures of supply chain performance. To achieve this, the present chapter describes process parameters used for analyzing the two staged supply chain and also presents detailed methodology related to design of experiment technique based on ANOVA method.

MODEL ANALYSIS

In the analysis a two staged real supply chain consisting of one supplier and four retailers was considered and simulated. In this study various conditions including various demand patterns, and various ordering costs were investigated in retailer's level. Ordering cost for each retailer was different from another retailer and also customer demand received by each retailer is independent from the other retailer because of the different geographical market of retailers. The simulation is done using MATLAB programming. In this project work, the following assumptions are made: The supplier can produce any required amount of the ordered products. Shipment was made from the supplier to the retailer by truck and it is assumed that the truck capacity is large enough, so that the ordered quantity in each period can be shipped

EXPERIMENTAL DESIGN

In conventional experiments, effect of only one factor is investigated independently at a time keeping all other factors at fixed levels. Therefore, visualization of impact of various factors in an interacting environment really becomes difficult. Thus, more experimental runs are required for the precision in effect estimation, general conclusions cannot be drawn and the optimal factor settings are difficult to obtain. To overcome this problem, design of experiment (DOE) approach is used to effectively plan and perform experiments, using statistics and is commonly used to improve the quality of products or processes. Design of experiments is a robust analysis tool for modeling and analyzing the influence of control factors on performance output. Bullwhip effect in supply chain is controlled by number of parameters which collectively determine the performance output. Hence, in the present work ANOVA's parameter design can be adopted to optimize the process parameters leading to reduction of bullwhip effect and mean square error. The most important stage in the DOE lies in the selection of the control parameters and their level. In the experimental design three factors that are holding cost (Cp), method and demand pattern (Pp) with four, ten and four levels are considered respectively. The levels of the factors are represented as shown in Tables 1.

Table 1: Representation of levels for the factor Cp

Level	Representation
$285	285
$361	361
$480	480
$583	583

CONCLUSION

It is observed from the above study that forecasting based demand variability is a major factor negatively influencing stability of supply chain network. In the present study, application of fuzzy logic reasoning using the ANOVA method for improvement of supply chain performance by reducing BWE and MSE has been studied. The optimization of the process parameters for minimum BWE and MSE were performed individually. Different forecasting methods have been compared from bullwhip effect and mean square error points of view by using simulation program written in MATLAB code, and then subsequently analyzed by fuzzy coupled with ANOVA for determining the optimal factors. The study uses ANOVA and a fuzzy-rule based inference system, which forms a robust and practical methodology in tackling multiple response optimization problems. It has been demonstrated that a multiple response optimization problem can be effectively tackled by using fuzzy reasoning to generate a single MPCI as a performance indicator. Statistical analysis is then carried out on the MPCI to identify the key factors, which affect process performance and then determine the optimal factor settings to optimize process performance.

REFERENCES

[1] Sterman, J.D., Misperceptions of feedback in dynamic decision making, Organizational behavior and human decision processes, 1989, 43(3), pp. 301-335.
[2] Towill, D.R., Supply chain dynamics, International Journal of Computer Integrated Manufacturing, 1991, 4(4), pp. 197-208.
[3] Towill, D.R., Supply chain dynamics—the change engineering challenge of the mid 1990s. ARCHIVE: Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 1989-1996 (vols 203-210), 1992, 206(42): pp. 233-245.
[4] Wikner, J., Towill, D.R. and Naim, M., Smoothing supply chain dynamics, International Journal of Production Economics, 1991, 22(3), pp. 231-248.
[5] Beamon B. M. (1998), "Supply chain design and analysis: Models and methods," International Journal of Production Economics, 55:281-294.
[6] Cachon G.P. (1999), "Quantitative models for supply chain management," Kluwer Academic Publishers, Boston, 111–146.
[7] Camm T., E. Chorman, F.A. Dill, J.R. Evans, D.J. Sweeney and G.W. Wegryn (1997), "Blending OR/MS judgment and GIS: Restructuring P&G's supply chain," International Journal of Production Economics, 27:128–142.
[8] Cantor, D.E. and J.R. MacDonald (2008), "Decision making in the supply chain: Examining problem solving approaches and information availability," Journal of Operations Managements, 26:461-556.
[9] Chen F., Drezner Z., J. Ryan and D. Simchi-Levi (1998), "Quantifying the bullwhip effect: The impact of forecasting, lead times and information," Management Science, 46:436-443.
[10] Cohen M. and L. Lee (1989), "Resource deployment analysis of global manufacturing and distribution networks," Journal of Manufacturing and Operations Management, 2:81–104.
[11] Harrell C.R. and K. Tumay (1994), "Simulation of manufacturing and service system," IE Management. Press, 5:114-121.
[12] Ishii K., K. Takahafhi and R. Muramatsu (1988), "Integrated production inventory and distribution system," International Journal of Production Research 26:473-482.
[13] Karabakal N., A. Gunal and W. Ritchie (2000), "Supply chain analysis of volkswagen of America," International Journal of Computer Integrated Manufacturing, 4:46–55.
[14] Karmarkar A. and N.R. Patel (1977), "The one-period, n-location distribution problem," Naval Research Logistics Quarterly, 24:559–575.
[15] Lee H., P. Padmanabhan and S. Whang (1997), "Information distortion in a supply chain: The bullwhip effect," Management Science, 5:546-58.