Results of a Beer Game Experiment: Should a Manager Always Behave According to the Book?

Mert Edali
Industrial Engineering Department
Yildiz Technical University
Besiktas – Istanbul 34349 – Turkey
Industrial Engineering Department
Bogazici University
Bebek – Istanbul 34342 – Turkey
medali@yildiz.edu.tr

Hakan Yasarcan
Industrial Engineering Department
Bogazici University
Bebek – Istanbul 34342 – Turkey
hakan.yasarcan@boun.edu.tr

Abstract

A supply chain is a series of connected stock management structures. Therefore, the structure of a supply chain consists of many cascading inventory management problems. It is known that the optimal inventory control parameter values suggested by the literature are also valid for a supply chain. The motivation for this study is to investigate the effect of the literature suggested optimal values of the parameters of a dynamic decision making heuristic in the presence of semi-rationally managed supply chain echelons. The Beer Game is a well known board game widely used for educational and experimental purposes. We employ a soft coded one-to-one version of The Beer Game as an experimental platform to carry out the study. We use a much longer time horizon than the one used in the board version of The Beer Game to prevent a potential short-term horizon effect. The results of the simulation runs carried out in this study do not support the use of the well-established decision parameter values for the echelon of concern if the other echelons' inventories are managed sub-optimally.

Keywords: anchor-and-adjust heuristic; beer game; stock adjustment fraction; stock management; supply chain management; weight of supply line.

1. Introduction

The Beer Game was introduced by Jay Forrester's System Dynamics research group of the Sloan School of Management at the Massachusetts Institute of Technology in the 1960s to be used in management education aiming to give the participants an experience about fundamental dynamic problems such as oscillating inventory levels and bullwhip effect (Akkermans and Vos 2003; Day and Kumar 2010; Jacobs 2000; Sterman 1989). The Beer Game is also used as an experimental platform in many studies to investigate the behavior of supply chains under many different settings. One of the main reasons of the wide use of The Beer Game is that it is capable of producing complex dynamics as demonstrated by many studies (Hwarng and Xie 2008; Hwarng and Yuan 2014; Mosekilde and Laugesen 2007; Thomsen et al. 1991).

The Beer Game is a four echelon supply chain consisting of a retailer, wholesaler, distributor, and factory where there is an inventory control problem for each one of these echelons. Therefore, the structure of the game consists of four cascading stock management problems. During the game, every participant in a group of four is responsible for one of the four echelons and manages the associated inventory by placing orders aiming to minimize the team cost. The orders flow from downstream echelons towards upstream echelons and cases of beer flow in the opposite direction. The accumulated total cost generated by each individual echelon is calculated at the end of the game by adding up all inventory holding and backlog costs obtained at the end of each simulated week and the team cost is obtained by summing up the total costs of the echelons (Croson and Donohue 2006; Edali 2014; Edali and Yasarcan 2014; Sterman 1989).

The original setting of The Beer Game can be classified under “traditional supply chain”, where there is no collaboration between the different echelons (Holweg et al. 2005). In addition, the demand pattern is almost constant throughout the game except that it jumps for only once from four to eight cases of beer in week 5. Different than the original Beer Game setting, Chen and Samroengraja (2000) used a stochastic end-customer demand pattern and informed all participants about the distribution of it, which was stationary. Croson and Donohue (2006) also used a stochastic end-customer demand pattern and they experimented with information sharing option. Steckel et al. (2004)

examined the effect of reduced cycle times and the effect of shared point-of-sale (POS) information among the supply chain members. Kim (2009) extended The Beer Game into a supply network and conducted agent-based simulations in his study. Ackere et al. (1993) applied business process redesign to The Beer Game and obtained many structurally different versions of it.

In this study, we employ a soft coded one-to-one version of *The Beer Game*, which simulates a production-distribution system, as an experimental platform (Edali and Yasarcan 2014). In our study, we stick to the original setting of The Beer Game except two differences:
(1) We have computer simulated decision makers instead of human participants; (2) We use a longer time horizon than the one used in the board version of the game.

In his famous Beer Game paper, Sterman (1989) suggests a stock control ordering policy, namely the *anchor-and-adjust heuristic*, to be used in managing the level of a stock. According to the results reported in that paper, the proposed heuristic is a good representation of the decision making processes of the participants who were managing inventories on a supply chain. Therefore, we represent the decision making processes of the computer simulated participants using the anchor-and-adjust heuristic. Note that the parameters of the anchor-and-adjust heuristic are called "decision parameters" in this study.

When all the four echelons of The Beer Game use the literature suggested optimal values of the decision parameters of the anchor-and-adjust heuristic in managing their respective inventories, the generated accumulated total cost is minimized. In this research, we investigate whether these optimal values still remain optimal for the echelon of concern if the rest of the team uses sub-optimal parameter values. Thus, the motivation for this study is to investigate the effect of the literature suggested optimal values of the decision parameters in the presence of semi-rationally managed supply chain echelons. This study diverts from the existing literature by assuming that the echelon of concern behaves different than the rest of the three echelons.

We first give a brief explanation about the selected time-horizon for the experiments (Section 2). Secondly, we provide a full description of the decision parameters of the anchor-and-adjust heuristic (Section 3). Thirdly, we present simulation results obtained under the first main setting, where the echelon of concern uses the literature suggested optimal decision making parameter values and the rest of the team uses the averages of the estimated parameter values of the participants of Sterman's (1989) Beer Game experiment (Section 4). Fourthly, we report simulation results obtained under the second main setting, where the echelon of concern uses the re-optimized decision making parameter values while the rest of the team behaves as in the first setting (Section 5). Later, the results given in sections 4 and 5 are compared (Section 6). In comparing the supply chain performances, we focus mainly on the team total cost values obtained under the two main settings. We also compare the individual total cost values of the echelon of concern. We iterate the experiment by switching the echelon of concern so as to obtain a set of total cost values under both settings for all the echelons. Finally, we report conclusions is Section 7.

2. The Time Horizon for the Experiments

The short-term and long-term benefits of a decision making strategy can be different (Gureckis and Love 2009). In other words, the short-term horizon and long-term horizon effects are not the same. "Among other results, we show that the short-term performance of a supply chain is not a predictor of the long-term performance even when decision makers fully recognize outstanding orders." (Macdonald et al. 2013). It is problematic to compare different settings in the short-term because even an essentially wrong decision making heuristic may outperform an essentially correct decision making heuristic in the short-run, but never in the long-run. The same argument is also true for essentially wrong and essentially correct parameter values of a decision making heuristic. Therefore, we select a much longer time horizon (520 weeks) than the one used in the board version of The Beer Game (36 weeks) in all simulation experiments, which hopefully will reduce the critics that we may receive.

3. The Decision Parameters and Their Values

Stock adjustment fraction[i] (α_s; also α_s in Sterman 1989), *weight of supply line* (*wsl*; β in Sterman 1989), *desired inventory* (I^*; S^* in Sterman 1989), and *smoothing factor* (θ; also θ in Sterman 1989) are the decision parameters of the anchor-and-adjust heuristic. For a complete description of the heuristic see Edali and Yasarcan (2014) and Sterman (1989). *Stock adjustment fraction* (α_s) is the intended fraction of the gap between the desired level of the stock and the current value of the stock to be closed every time unit (per week in The Beer Game). The inverse of the parameter α_s (i.e., α_s^{-1}) represents the number of weeks in which a decision maker wants to bring his current inventory level to its desired value. Comparatively, small values of α_s result in mild corrections, while higher values of it correspond to aggressive corrections. According to the literature (see, for example, Sterman 1989), the optimum value of this parameter is one per unit of time (i.e., per week). Therefore, α_s is taken as one per week for the echelon of concern in the first setting.

Weight of supply line (*wsl*) represents the relative importance given to the supply line compared to the main stock. In other words, *wsl* is the fraction of supply line considered in the control decisions (i.e., order decisions). When *wsl* is taken as one, the main stock and its supply line will be effectively reduced to a single stock that cannot oscillate (Barlas and Ozevin 2004; Sterman 1989; Yasarcan and Barlas 2005a and 2005b). However, a zero value of *wsl* means that supply line is totally ignored in decision-making process and it may potentially create an unstable stock behavior. According to Sterman (1989), the optimum value of this parameter is unity. Therefore, *wsl* is taken as unity for the echelon of concern in the first setting.

This study focuses mainly on the values of α_s and *wsl*. Accordingly, the motivation for this study is to investigate the performance of the literature suggested optimal values of α_s and *wsl* (i.e., one per week and unity) in the presence of semi-rational supply chain partners (i.e., $\alpha_s \neq 1$ per week and $wsl \neq 1$). In both settings, α_s and *wsl* values for the echelons other than the echelon of concern are taken as 0.26 per week and 0.34,

[i] In many studies, *Stock adjustment time* (*sat*) is used instead of *Stock adjustment fraction* (α_s), which essentially makes no difference in the anchor-and-adjust heuristic because $sat = \alpha_s^{-1}$ (Edali and Yasarcan 2014).

respectively. These values are the averages of the estimated parameter values of the participants of The Beer Game (Sterman 1989).

Desired inventory (I^*) is another parameter of the anchor-and-adjust heuristic and it simply represents the target inventory level. In The Beer Game, the cost function is asymmetric; *unit backlog cost* is \$1.00/(case·week) while *unit inventory holding cost* is \$0.50/(case·week). Therefore, it is usually less costly to have a positive on-hand inventory than having a backlog. Comparatively speaking, a better control decreases the requirement for large values of I^* while a worse control increases this requirement. The value of I^* is assumed to be 0 for all echelons in both settings. The reason for selecting $I^* = 0$ is that if inventory and backlog are both zero for an echelon in a simulated week, that echelon produces no costs in that week. In this study, we do not experiment with the assumed value of this parameter.

Smoothing factor (θ) is the main parameter of exponential smoothing forecasting method and it represents the weight given to recent observations in the forecasting process. Although smoothing-factor is one of the parameters of the anchor-and-adjust heuristic, its optimization is out of the scope of this study. Theoretically, θ can take a value between 0 and 1. A zero value of θ means no corrections in the forecasted values. On the other hand, when it is taken as one, the exponential smoothing method will be equivalent to a naive forecast. It may not be practical to use a randomly selected *smoothing factor* value, even if that value fall in the theoretical range. According to Gardner (1985), the *smoothing factor* of a simple exponential smoothing forecasting method should be between 0.1 and 0.3 in practice. As a reasonable value, we suggest using a *smoothing factor* of 0.2 in forecasting, which is the middle point of the range suggested by Gardner (1985). This value of *smoothing factor* also falls in the range of 0.01 and 0.3 that is suggested by Montgomery and Johnson (1976). Therefore, θ is taken as 0.2 for the echelon of concern in both settings. The value of θ for the echelons other than the echelon of concern is taken as 0.36 per week in both settings. This value is the average of the estimated θ values of the participants of The Beer Game (Sterman 1989).

4. Setting 1: Results for the Literature Suggested Optimal Values of α_s and *wsl*

In these experiments, the optimal value of α_s that is one per week and the optimal value of *wsl* that is unity are used as the decision parameter values of the echelon of concern. The α_s and *wsl* values of the other three echelons (i.e., the semi-rationally managed supply chain echelons) are taken as 0.26 per week and 0.34, respectively. The results are reported in Table 1. The experiment is repeated for all the echelons by switching the echelon of concern for each simulation run.

Table 1. Total cost values when the echelon of concern uses the literature suggested optimal parameter values (i.e., α_s = 1 per week and *wsl* = 1)

The echelon of concern	Total Team Cost ($)	Total Cost of Retailer ($)	Total Cost of Wholesaler ($)	Total Cost of Distributor ($)	Total Cost of Factory ($)
Retailer	4,715.00	701.00	1,056.50	1,603.00	1,354.50
Wholesaler	34,684.50	6,909.50	9,611.00	9,955.00	8,209.00
Distributor	33,302.00	4,919.50	9,162.50	10,192.50	9,027.50
Factory	32,937.50	4,401.00	8,094.50	11,808.00	8,634.00

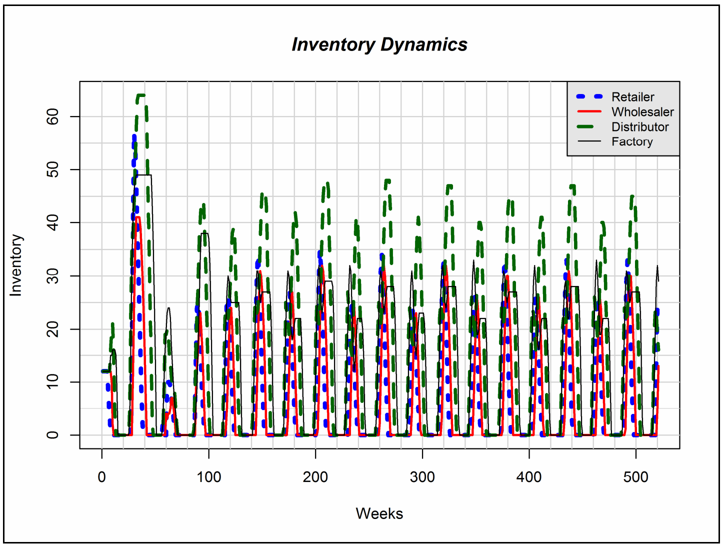

Fig. 1 The dynamics of the inventories when the wholesaler is using the literature suggested optimum values

Extremely high costs are obtained when the echelon of concern is the wholesaler, the distributor, or the factory. The reason behind these high cost values is the oscillations in the dynamics as it can be observed from figures 1, 2, and 3. Note that the dynamics presented in figures 1, 2, and 3 comes from the trial in which the wholesaler is the echelon of concern. The dynamics for the trials, in which the distributor or the factory is the echelon of concern, are very similar to the ones presented in figures 1, 2, and 3. Hence, they are excluded from the paper. The dynamics for the trial, in which the retailer is the echelon of concern, is less oscillatory and similar to the dynamics shown in the figures 4, 5, and 6.

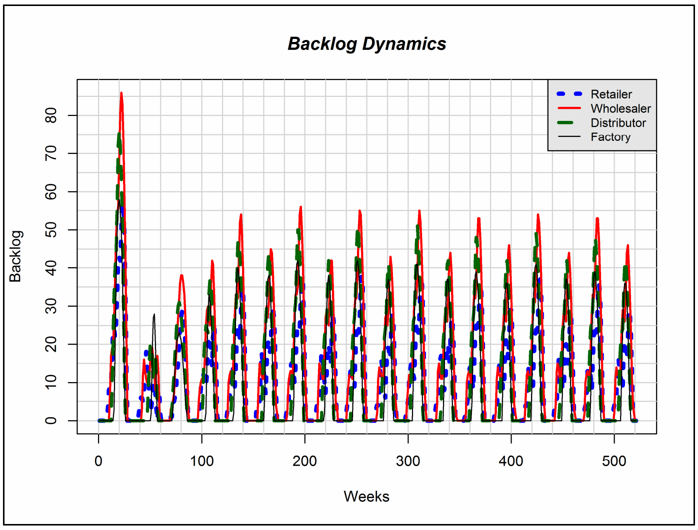

Fig. 2 The dynamics of the backlogs when only the wholesaler is using the literature suggested optimum values

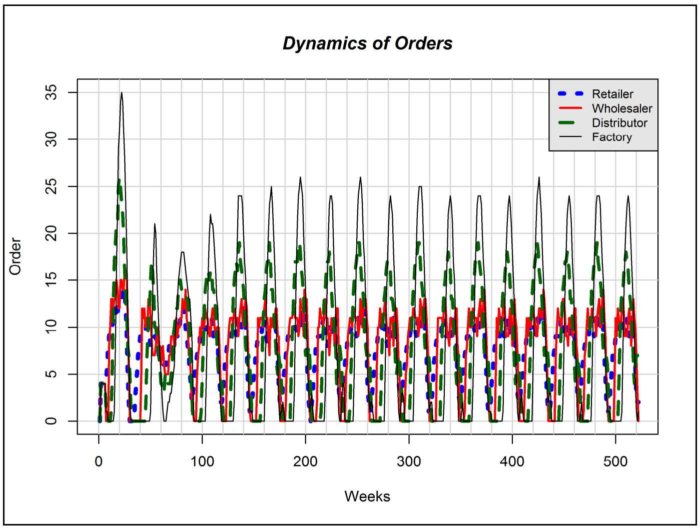

Fig. 3 The dynamics of the orders when only the wholesaler is using the literature suggested optimum values

5. Setting 2: Results for the Re-Optimized Values of α_s and *wsl*

In these experiments, the optimal value of α_s that is one per week and the optimal value of *wsl* that is unity are not used as the decision parameter values of the echelon of concern. Instead, they are re-optimized for each of the four trials with a different echelon of concern. In all trials under setting 2, similar to the experiments in the previous section, the α_s and *wsl* values of the other three echelons are taken as 0.26 per week and 0.34, respectively. The results are reported in Table 2.

Table 2. Total cost values when the echelon of concern uses the re-optimized values of α_s and *wsl*

The echelon of concern	α_s of the echelon of concern (per week)	*wsl* of the echelon of concern	Total Team Cost ($)	Total Cost of Retailer ($)	Total Cost of Wholesaler ($)	Total Cost of Distributor ($)	Total Cost of Factory ($)
Retailer	0.04	0.45	4,549.00	845.00	1,006.00	1,469.50	1,228.50
Wholesaler	0.09	0.07	7,320.00	1,188.50	2,222.50	1,974.00	1,935.00
Distributor	0.52	0.95	7,535.50	1,125.50	2,104.00	2,212.50	2,093.50
Factory	0.95	0.78	7,605.50	1,111.50	1,756.00	2,683.00	2,055.00

The extreme costs reported in Table 1 are eliminated when the re-optimized parameter values are used (Table 2). The reason behind the decrease in the costs values is caused by the damping oscillations as it can be observed from figures 4, 5, and 6. Note that we again present only the dynamics for the trial in which the wholesaler is the echelon of concern because these dynamics are representative of the dynamics obtained in other trials.

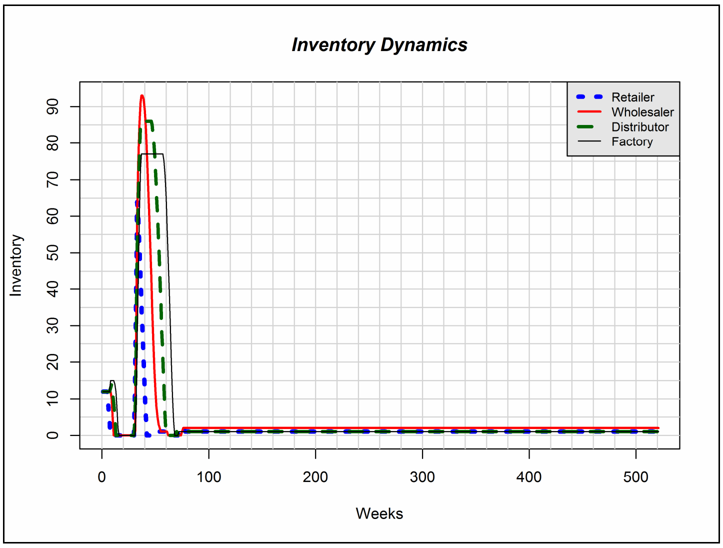

Fig. 4 The dynamics of the inventories when the wholesaler is using the re-optimized parameter values

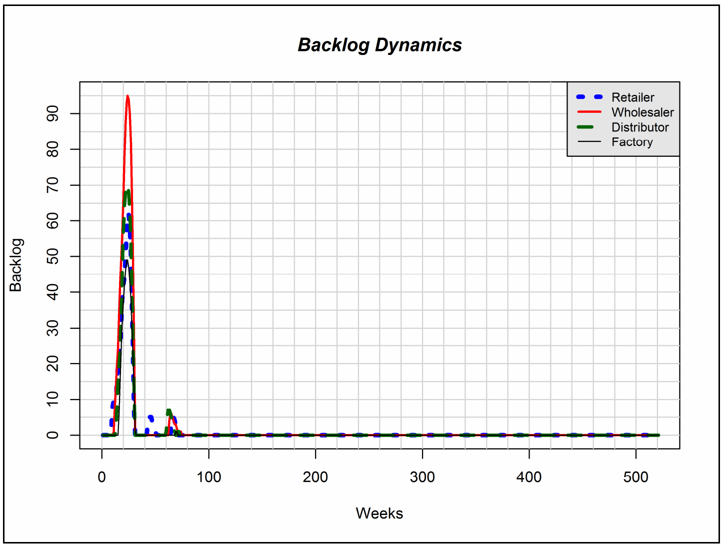

Fig. 5 The dynamics of the backlogs when the wholesaler is using the re-optimized parameter values

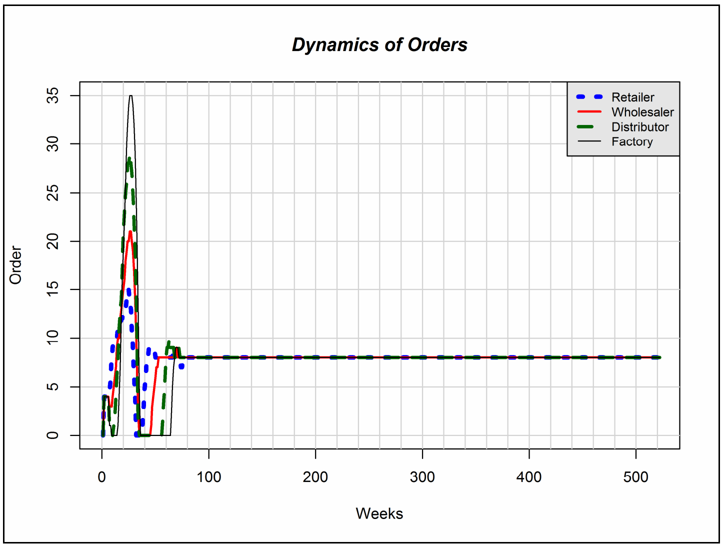

Fig. 6 The dynamics of the orders when the wholesaler is using the re-optimized parameter values

6. Comparisons

In this study, we carry out Beer Game experiments using a long-term horizon, 520 weeks. In the experiments, we assumed that all echelons are managed by semi-rational decision makers (α_S = 0.26 per week and *wsl* = 0.34) except for the echelon of concern. In the first setting, the echelon of concern is managed by a rational decision maker (i.e., α_S = 1 per week and *wsl* = 1) who behaves according to the book (i.e., the literature). However, in the second setting, the decision maker managing the echelon of concern uses re-optimized decision making parameter values. In all of the four trials under the second setting, where either one of the retailer, wholesaler, distributor, or factory is selected as the echelon of concern for each trial, the parameter values obtained for the echelon of concern depict a semi-rational decision maker according to the literature (i.e., $\alpha_S \neq 1$ per week and $wsl \neq 1$). Thus, a semi-rational decision maker obtains better results than a manager who behaves according to the book in the presence of semi-rationally managed supply chain echelons.

If the echelon of concern is the retailer and if the decision maker uses the literature suggested optimal parameter values in managing the inventory level of this position, the total cost generated for the retailer at the end of the game would be \$701 and the total team cost would be \$4,715 (Table 1). If this decision maker uses the re-optimized parameter values given in Table 2 (α_s = 0.04 per week and *wsl* = 0.45), these cost values would be \$845 and \$4,549, respectively. Therefore, if the retailer accepts a 20.54% increase in its own costs and uses α_s = 0.04 per week and *wsl* = 0.45 instead of α_s = 1 per week and *wsl* = 1, a 3.52% decrease in the total cost can be obtained for the whole supply chain.

If the echelon of concern is the wholesaler and if the decision maker uses the literature suggested optimal parameter values in managing the inventory level of this position, the total cost generated for the wholesaler at the end of the game would be \$9,611 and the total team cost would be \$34,684.50 (Table 1). If this decision maker uses the re-optimized parameter values given in Table 2 (α_s = 0.09 per week and *wsl* = 0.07), these cost values would be \$2,222.50 and \$7,320, respectively. Therefore, if the wholesaler uses α_s = 0.09 per week and *wsl* = 0.07 instead of α_s = 1 per week and *wsl* = 1, a 76.88% decrease in its own costs and a 78.90% decrease in the team total cost can be obtained.

If the echelon of concern is the distributor and if the decision maker uses the literature suggested optimal parameter values in managing the inventory level of this position, the total cost generated for the distributor at the end of the game would be \$10,192.50 and the total team cost would be \$33,302 (Table 1). If this decision maker uses the re-optimized parameter values given in Table 2 (α_s = 0.52 per week and *wsl* = 0.95), these cost values would be \$2,212.50 and \$7,535.50, respectively. Therefore, if the distributor uses α_s = 0.52 per week and *wsl* = 0.95 instead of α_s = 1 per week and *wsl* = 1, a 78.29% decrease in its own costs and a 77.37% decrease in the team total cost can be obtained.

If the echelon of concern is the factory and if the decision maker uses the literature suggested optimal parameter values in managing the inventory level of this position, the total cost generated for the factory at the end of the game would be \$8,634 and the total team cost would be \$32,937.50 (Table 1). If this decision maker uses the re-optimized parameter values given in Table 2 (α_s = 0.95 per week and *wsl* = 0.78), these cost values would be \$2,055 and \$7,605.50, respectively. Therefore, if the factory uses α_s = 0.95 per week and *wsl* = 0.78 instead of α_s = 1 per week and *wsl* = 1, a 78.29% decrease in is own costs and a 77.37% decrease in the team total cost can be obtained.

7. Conclusions

According to the literature, a "rational manager" must use "α_s = 1 per week and *wsl* = 1" in managing an inventory. Moreover, the sub-optimal decision making processes (i.e., $\alpha_s \neq 1$ per week and $wsl \neq 1$) of human decision makers (i.e., semi-rational mangers) is criticized. According to our results, it is possible for a "rational manager" to create almost five times the costs obtained by a "semi-rational manager". The surprising findings of this study indicate that the criticisms in the literature are implicitly based on the assumption that it is possible for all echelons to determine and agree on using the decision making parameter values that are globally optimal. First of all, determining the globally optimum parameter values in a real-life setting is not an easy task, perhaps impossible in many cases. Secondly, in most cases, it will not be possible to make all supply chain members to reach to a perfect agreement on using the globally optimum parameter values. Therefore, in a real life situation, a manager must not blindly behave according to the book (i.e., must not imprudently use the literature suggest decision making parameter values). We suggest that a manager must be aware of the literature, but must not give up his own judgment and must not blindly follow it. On the contrary, he will most probably achieve good results if he combines the information reported in the literature with his own experience and instincts. We hope that our study will trigger further studies in analyzing the effects of the literature suggested optimum behaviors under imperfect realistic settings.

Acknowledgements

This research is supported by a Marie Curie International Reintegration Grant within the 7th European Community Framework Programme (grant agreement number: PIRG07-GA-2010-268272) and also by Bogazici University Research Fund (grant no: 6924-13A03P1).

This paper was also published by Bogazici University (Edali and Yasarcan, 2015).

References

Ackere AV, Larsen ER, Morecroft, JDW (1993) Systems thinking and business process redesign: An application to the beer game. Eur Manag J 11(4):412-423. doi:10.1016/0263-2373(93)90005-3

Akkermans H, Vos B (2003) Amplification in service supply chains: An exploratory case study from the telecom industry. Prod Oper Manag 12(2):204-223. doi:10.1111/j.1937-5956.2003.tb00501.x

Barlas Y, Ozevin MG (2004) Analysis of stock management gaming experiments and alternative ordering formulations. Syst Res Behav Sci 21(4):439-470. doi:10.1002/sres.643

Chen F, Samroengraja R (2000) The stationary beer game. Prod Oper Manag 9(1):19-30. doi:10.1111/j.1937-5956.2000.tb00320.x

Croson R, Donohue K (2006) Behavioral causes of the bullwhip effect and the observed value of inventory information. Manag Sci 52(3):323-336. doi:10.1287/mnsc.1050.0436

Day JM, Kumar M (2010) Using SMS text messaging to create individualized and interactive experiences in large classes: A beer game example. Decis Sci J Innov Educ 8(1):129-136. doi:10.1111/j.1540-4609.2009.00247.x

Edali M. (2014). Decision Making Implications for a Selected Echelon in the Beer Game, M.S. Thesis, Bogazici University.

Edali M, Yasarcan H (2014) A mathematical model of the beer game. J Artif Soc Soc Simul 17(4):2. <http://jasss.soc.surrey.ac.uk/17/4/2.html>.

Edali M, Yasarcan H (2015) Results of a Beer Game Experiment: Should a Manager Always Behave According to the Book? Research Paper Series No: FBE-IE-01/2015-02, Bogazici University, Istanbul.

Gardner ES (1985) Exponential smoothing: The state of the art. J Forecast 4(1):1-28. doi:10.1002/for.3980040103

Gureckis TM, Love BC (2009) Short-term gains, long-term pains: How cues about state aid learning in dynamic environments. Cogn 113(3):293-313. doi:10.1016/j.cognition.2009.03.013

Holweg M, Disney S, Holmström J, Småros J (2005) Supply chain collaboration: Making sense of the strategy continuum. Eur Manag J 23(2):170-181. doi:10.1016/j.emj.2005.02.008

Hwarng HB, Xie N (2008) Understanding supply chain dynamics: A chaos perspective. Eur J Oper Res 184(3):1163-1178. doi:10.1016/j.ejor.2006.12.014

Hwarng HB, Yuan X (2014) Interpreting supply chain dynamics: A quasi-chaos perspective. Eur J Oper Res 233(3):566-579. doi:10.1016/j.ejor.2013.09.025

Jacobs FR (2000) Playing the beer distribution game over the internet. Prod Oper Manag 9(1):31-39. doi:10.1111/j.1937-5956.2000.tb00321.x

Kim W-S (2009) Effects of a trust mechanism on complex adaptive supply networks: An agent-based social simulation study. J Artif Soc Soc Simul 12(3):4. <http://jasss.soc.surrey.ac.uk/12/3/4.html>.

Macdonald JR, Frommer ID, Karaesmen IZ (2013) Decision making in the beer game and supply chain performance. Oper Manag Res 6(3-4):119-126. doi:10.1007/s12063-013-0083-4

Montgomery DC, Johnson LA (1976) Forecasting and Time Series Analysis. McGraw-Hill, New York.

Mosekilde E, Laugesen JL (2007) Nonlinear dynamic phenomena in the beer model. Syst Dyn Rev 23(2-3):229-252. doi:10.1002/sdr.378

Steckel JH, Gupta S, Banerji A (2004) Supply chain decision making: Will shorter cycle times and shared point-of-sale information necessarily help? Manag Sci 50(4):458-464. doi:10.1287/mnsc.1030.0169

Sterman JD (1989) Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. Manag Sci 35(3):321-339. doi:10.1287/mnsc.35.3.321

Thomsen JS, Mosekilde E, Sterman JD (1991) Hyperchaotic phenomena in dynamic decision making. In: E. Mosekilde & L. Mosekilde (eds.) Complexity, Chaos, and Biological Evolution. Plenum Press, New York, pp 397-420.

Yasarcan H, Barlas Y (2005a) A generalized stock control formulation for stock management problems involving composite delays and secondary stocks. Syst Dyn Rev 21(1):33–68. doi:10.1002/sdr.309

Yasarcan H, Barlas Y (2005b) Stable stock management heuristics when the outflow is proportional to the control stock. Paper presented at the 23rd International System Dynamics Conference, Boston, MA.