ACHIEVING DYNAMIC STABILITY OF SUPPLY CHAINS IN THE WHIRLPOOL CHANGES

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Abstract

Modern supply chains are exposed to a changing competitive environment dominated by health, military, political, economic, and other swirling changes that are almost impossible to control. Business stability in such conditions takes on a completely different meaning. The supply chain's dynamic stability means its participants' ability to quickly and efficiently adapt to turbulent changes. Accordingly, this paper will specifically investigate the impact of inflation and negative market conditions on supply chain operations. This work's main hypothesis is that supply chains can successfully manage overall change by achieving dynamic stability. The results of the research are based on the method of dynamic programming and the method of simulation. The main finding of this paper points to the conclusion that by achieving dynamic stability, supply chains are able to operate successfully even in negative market conjuncture.

Keywords: supply chains, dynamic stability, inflation, market conjuncture

1. INTRODUCTION

A supply chain consists of all parties (manufacturers, suppliers, transporters, warehouses, retailers, and customers) and, within each organization, all the functions involved, directly or indirectly, in fulfilling a customer request (Chopra and Meindl 2010). Supply chains can operate under conditions of static and dynamic stability. Unlike traditional supply chains, which can be said to have operated in static stability conditions, modern supply chains operate in conditions of disturbed stability, extreme dynamism, and almost whirlwind changes. Changed business conditions require traditional supply chains built for relatively stable business conditions to reorganize and achieve dynamic stability as a fundamental prerequisite for achieving their business goals. According to (Abrahamson, 2000), "dynamic stability is a process of continual but relatively small change efforts that involve the reconfiguration of existing practices and business models rather than the creation of new ones." Supply chain managers have to create a dynamic stable network that is capable to implement big and small changes at the right time and right place. A dynamic supply chain anticipates changes in its global, regional, and national environment, developing full visibility, agility, and resilience.

A research hypothesis is: Supply chains can successfully manage unexpected changes in the business environment by achieving dynamic stability.

This paper aims to address the following research questions:

- How to reduce supply chain disruption?
- How to optimize supply chain in disruption conditions?
- What are the main differences in the operation of an optimized supply chain in conditions of dynamic and static stability?
- How to mitigate the next global supply chain disruption that will come?

The results of the research are based on the method of dynamic programming and the method of simulation. The method of dynamic programming was chosen for the reason that it enables step-by-step cost minimization within the supply chain. However, as the application of the dynamic programming method requires numerous calculations for the purposes of this scientific discussion, a computer model was developed in an MS Excel spreadsheet. The application of simulation based on a computer-supported model will be presented to solve a complex business problem with the aim of achieving dynamic stability of the supply chain in turbulent business conditions.

2. LITERATURE REVIEW

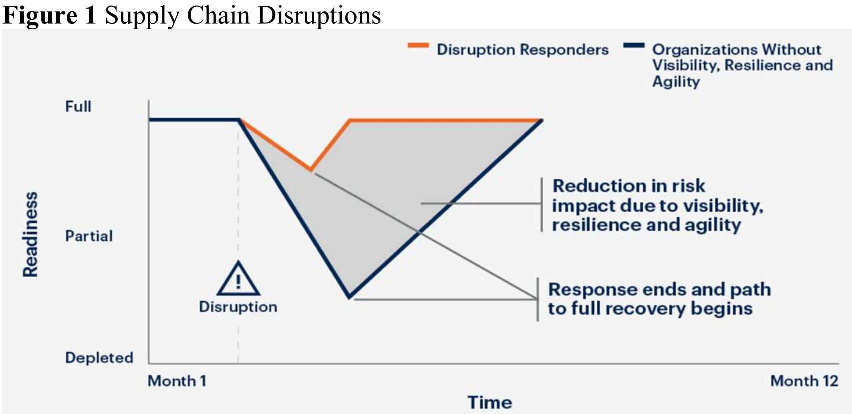
At the beginning of the 21st century, supply chains become one of the most important topics of investigation. Traditional supply chains do business in relatively stable environments, seeking to achieve stability and minimize costs. Future supply chains will need to be much more dynamic—and be able to predict, prepare, and respond to rapidly evolving demand and a continually changing product and channel mix. In short, supply chains will need to achieve agility, visibility and resilience. The capacity to detect and respond promptly to supply chain disruptions while limiting risk implications is referred to as agility. Visibility ensures that the supply chain detects threats early and is aware of the best reaction options so that it can respond appropriately. The ability to withstand, absorb, and recover from supply chain disturbance is referred to as resilience.

In the relatively stable business environment in which traditional supply chains were created and developed, the emphasis was on inventory management and control (Eilon, 1961). Increasing fluctuations in demand will direct researchers to manage production and develop dynamic models for production planning (Bedini & Toni, 1980). These models are based on demand planning, capacity planning, material planning, etc. The end of the 20th and the beginning of the 21st century will mark the end of stability in business, and uncertainty and disruption will begin to play an increasingly important role in supply chain management. Instabilities as well as unreliable suppliers are increasingly becoming the subject of research (Benyoucef, Xie, Tanonkou, 2013). The global financial crisis of 2008 will mark the path into the unknown. Global trade is down by a third in 2009 from 2008 (The Economist, 2009). This is leading active participants in supply chains to refocus on stability and risk management (Pisano-Ferry & Santos, 2009). Accordingly, Kleindorfer and Saad (2009) investigate risks arising from disruptions to normal activities which may arise from natural disasters, from strikes and economic disruptions, and from acts of purposeful agents, including terrorists. Supply chain resilience is one of the main issue in the current supply chain management (Melnyk et al. 2014; Ivanov, 2018).

The COVID-19 crisis will cause previously unimaginable disruptions in supply chains. For example, 94% of the Fortune 1000 companies faced supply chain disruption due to COVID-19 (Fortune, 2020). In supply chain management disruption events and recovery policy start to play a crucial role (de Sousa Jabbour et al., 2020). COVID-19 crises triggered supply chain disruption and caught many companies off guards (https://sloanreview.mit.edu). Shekarian & Parast (2021) identified flexibility and collaboration as the most important strategy to cope with supply chain disruptions. Dynamic stability can enable active participants in the supply chain to obtain, and maintain, stable and lasting competitive advantages (Hu and Fun, 2023).

The war in Ukraine and the associated inflation threaten permanent instability. The war produced disruption in regional supply chains and increased the risks to global growth (Guenette, Kenworthy, Wheeler, 2022). In a whirlwind environment, changes are so frequent and fast that it is almost impossible to keep track of them. Change is the only constant in modern business. Financial, health, military, political, economic, and other whirlwind changes point to the necessity of searching for models that guarantee the establishment of dynamic stability. Aslam, et al. (2022) see the dynamic capabilities of the supply chain as the key factor to raise the level of supply chain competition. Dynamic stability is the main prerequisite for the reduction in risk and quick response to supply chain disruptions (cf. figure 1).

Figure 1 Supply Chain Disruptions



Source: Gartner, 2021.

Based on Figure 1, it is clear that supply chains that are unable to achieve visibility, agility, and resilience, that is, to establish dynamic stability, expose their business to high risk, lose their competitive position, and question their viability on the market. Dynamic stability means a high level of readiness of the supply chain for a quick response to the whirlwind changes in the environment and the path to full recovery. Supply chain managers now have full attention of top management and mandate to redesigning their supply chains. Resilience, agility, and sustainability are key factors in the transition to dynamic stability (Heinrich, at al, 2022).

3. MATHEMATICAL MODEL

The optimization of the supply chain is reduced to the problem of determining the optimal amount of production in time (x_t), with the condition that procurement costs (n_t, t = 1.2, ..., T), production costs (c_t, t = 1.2, . .., T), costs of keeping stocks of finished products (will appear in case production x_t is greater than demand d_t, $F(x_t-d_t)$, t = 1, 2, ..., T), transportation costs (t_t , t = 1, 2, ..., T) and costs of unsatisfied demand (will appear in the event that demand d_t is greater than production x_t, $F_1(d_t-x_t)$, t = 1, 2, ..., T) be minimal.
All constraints relevant to the production process within the supply chain must also be satisfied.

As far as restrictions are concerned, it is assumed that there are restrictions regarding the maximum possible production (Q_t, t = 1, 2, ..., T), minimum and mandatory production (q_t, t = 1, 2, ..., T) in each period.

Accordingly, the following restrictions are set

$$q_t \leq x_t \leq Q_T \qquad t = 1, 2, ..., T,$$

or

$$x_t \geq q_t \text{ i } x_t \geq Q_t, t = 1, 2, ..., T.$$

In each, even the T-period, of the production process within the supply chain, there are two different possibilities for the organization of production, namely:

1) The known demand d_T will be satisfied, and then procurement costs, production costs, storage costs, and transport costs may appear, which should be minimized, which can be represented mathematically in the following way:

   $$\min \{F(S - d_t + x_t) + n_T c_T t_T x_T\},$$

   with constrains

   $$x_T \geq d_T\text{-}S,$$
   $$q_T \leq x_T \leq Q_T,$$

where S is the number of products produced in the previous periods and delivered in the T-th period.

2) Known demand does not have to be met, so there will be costs of unfulfilled demand (costs of lost sales), procurement costs, production costs, and transport costs, and this can be represented mathematically as follows:

$$\min \{F_1(d_t - S - x_t) + n_T c_T t_T x_T\},$$

with constrains

$$x_T \leq d_T - S,$$
$$q_T \leq x_T \leq Q_T.$$

It implies that of these two possibilities, one should choose the one that will give lower total costs of the supply chain, which means that the recursive form $f_T(S)$, which minimizes the total costs in the T-th period, can be written as

$$f_T(S) = \min \begin{Bmatrix} \min\{F(S\ \ d_t + x_t) + n_T c_T t_T x_T\} \\ x_T \geq d_T - S \\ \min \{F_1(d_t\ - S - x_t) + n_T c_T t_T x_T\} \\ x_T \leq d_T - S \end{Bmatrix}$$

with constrains

$$q_T \leq x_T \leq Q_T.$$

4. DATA AND RESEARCH METHODOLOGY

For the purpose of this scientific debate we present next practical example. Supply chain has recognised in the Middle East market certain demand for the product A. Market price of the product is 23 €. Six-month' demand for the product A are shown table 1.

Table 1 Demand for the product A on the Midlle East market (in 000)

January	February	March	April	May	June
136	92	88	138	116	132

Source: Authors

All the participants of supply chain are aware of all expenses within certain supply chain (table 2).

Table 2 Unit costs per one product A

Unit costs	Jan.	Feb.	March	April	May	June
Procurement	3,5	3,5	3,4	3,4	3,4	3,4
Production	8,2	8,2	8	7,8	7,5	7,5
Inventory	1,5	1,5	1,4	1,3	1,3	1,3
Transport	4	4	3,8	3,8	3,9	4
Lost Sales	1,8	1,8	2,1	1,7	2,3	2,3

Source: Authors

Within an established supply chain there are limitation regarding maximum possible and obligatory monthly production (table 3.):

Table 3 Production limits and obligatory production within certain supply chain (in 000)

	Jan.	Feb.	March	April	May	June
Q_t	140	144	148	152	156	156
q_t	60	56	70	56	60	60

Source: Authors

Further to the information presented, it is necessary to determine optimum quantity of production during next six months (t = 1, 2, 3, 4, 5, 6) in a way that a supply chain gains the largest possible profit, and at the end of the said period has 15 000 product A in stock.

The assumption is that within the first two months, business will be conducted in a stable business environment, that is, in conditions of static stability. In the third month, inflation will appear, which will mark an increase in the prices of all goods and services in the supply chain at a rate of 6%. Inflation is expected to be an additional 6.5% in the fourth month, an additional 4% in the fifth, and only 1.5% in the sixth. The increase in the selling price of the supply chain will occur only in the fourth month, immediately by 10%, in the fifth month by an additional 6%, and in the sixth month by 0.75%. Inflation and the associated increase in sales prices will result in a decrease in demand for the supply chain product by 5% in the fifth month and by an additional 10% in the sixth month compared to the forecasted demand. In such conditions, for speculative reasons, the supply chain decided to increase the stock at the end of the observed period from 15 to 30 thousand products.

The problem posed in this way is solved by dynamic programming methods, i.e. by applying appropriate recursive relations, which help to minimize the costs of the supply chain in stages. However, as the application of the dynamic programming method requires numerous calculations for the purposes of this scientific discussion, a computer model was developed in an MS Excel spreadsheet. The application of simulation based on a computer-supported model will be presented to solve the presented business problem with the aim of achieving the dynamic stability of the supply chain.

5. RESEARCH RESULTS

To create a simulation for the mentioned business problem, the Excel spreadsheet is a very useful tool. A good computer simulation is the cheapest way to test different business actions and identify the most effective decisions. Solving the problem can be approached in two ways: 1) by setting up a general model that corresponds to the conditions of stable business and 2) by setting up a modified model that corresponds to the conditions of unstable business. Due to the limited space in this scientific discussion, we will immediately proceed to set up a modified model that corresponds to the conditions of vortex unstable business (cf. table 4).

Table 4 Model of dynamic optimization of the supply chain in unstable business conditions

	A	B	C	D	E	F	G	H
1	Economic climate					95%	85%	
2	Rate of inflation			1.065	1.125	1.165	1.17	
3	Market price	23	23	23	25.3	26.82	27.02	
4	**Unit costs**	Jan	Feb	March	April	May	June	
5	Procurement	3.5	3.5	3.4	3.4	3.4	3.4	
6	Production	8.2	8.2	8	7.8	7.5	7.5	
7	Inventory	1.5	1.5	1.4	1.3	1.3	1.3	
8	Transport	4	4	3.8	3.8	3.9	4	
9	Lost Sales	1.8	1.8	2.1	1.7	2.3	2.3	
10								
11	Obligatory production	60	56	70	56	60	60	
12	Optimal production	0	0	0	0	0	0	
13	Max production	140	144	148	152	156	156	
14								
15	Initial inventory	15	0	0	0	1	0	
16	Monthly demand	136	92	88	138	110	112	
17	Ending inventory	0	0	0	0	0	0	30
18		0	0	0	0	0	0	
19		0	0	0	0	0	0	
20								
21	Procurement costs							
22	Production costs							
23	Inventory costs							
24	Transport costs							
25	Lost Sales costs							

26	Total monthly costs							
27						TOTAL	PROFIT	

Source: Authors

In the header of the table (A1:G3), the conditions from the business environment that will determine the operation of the supply chain in the next six-month period are first entered, namely: market conditions, inflation, and the movement of market prices. After that, in the address areas B5:G5, B6:G6, B7:G7, B8:G8, and B9:G9, it is necessary to enter the unit costs of procurement, production, inventory, transportation, and lost sales. Then, data on mandatory production is entered in the address area B11:G11. Address area B12:G12 contains decision variables, and address area B13:G13 data on maximum possible production for each period. The initial stocks for the first month are known and given in the address field B15, while the stocks at the end of the month are determined by the formula =B12+B15-B16. The specified formula is copied to the address area B17:G17. Closing stocks at the end of a month represents the beginning stocks of the following month. In the address field B18 there is the formula =IF(B17>0; B17;0), which is copied to the entire address area B18:G18. This formula determines the size of the inventory (if it exists) in order to be able to calculate the associated costs. Likewise, the address field B19 contains the formula =IF(B17<0;-B17;0), in order to calculate the cost of lost sales for each period. That formula is copied into the address area B19:G19.

The address area B21:G25 contains the appropriate formulas to calculate the monthly costs of procurement, production, inventory, transportation, and lost sales, while the address area B26:G26 contains the formulas needed to calculate the total six-month costs of procurement, production, inventory, transportation and lost sales selling. Address area H27 contains the formula =B3*SUM(B16:D16)+E3*E16+F3*F16+G3*G16-H26, which calculates the total profit of the supply chain and at the same time represents the objective function (it needs to be maximized).

After the dynamic optimization model has been formulated in the spreadsheet in the Tools menu, the Solver program is called and data entry is accessed in the Solver Parameters tab.

Set Target Cell: H27
Equal To: Max
By Changing Cells: B12:G12
Subjects to the Constraints:
B12:G12 ≤ B13:G13
B12:G12 ≥ B11:G11
B12:G12 ≥ 0
B12:G12 =integer
G17 = H17

When all parameters have been entered, click on the Solve button of the Solver Parameters form, which activates the Solver program that calculates the value of the decision variables in the address sequence B12:G12. The decision variables that are calculated in the address sequence B12:G12 define the optimal solution. Table 5 shows the optimal solution to the problem using an MS Excel spreadsheet.

Table 5 The optimal solution for supply chain production in unstable business conditions

	A	B	C	D	E	F	G	H
1	Economic climate					95%	85%	
2	Rate of inflation			1,065	1,125	1,17	1,17	
3	Market price	23	23	23	25,3	26,8	27,02	
4	**Unit costs**	Jan	Feb	March	April	May	June	
5	Procurement	3,5	3,5	3,4	3,4	3,4	3,4	
6	Production	8,2	8,2	8	7,8	7,5	7,5	
7	Inventory	1,5	1,5	1,4	1,3	1,3	1,3	
8	Transport	4	4	3,8	3,8	3,9	4	
9	Lost Sales	1,8	1,8	2,1	1,7	2,3	2,3	
10								
11	Obligatory production	60	56	70	56	60	60	
12	Optimal production	121	92	88	138	110	142	691
13	Max production	140	144	148	152	156	156	
14								
15	Initial inventory	15	0	0	0	0	0	
16	Monthly demand	136	92	88	138	110	112	676
17	Ending inventory	0	0	0	0	0	30	30
18		0	0	0	0	0	30	
19		0	0	0	0	0	0	
20								
21	Procurement costs	423,5	322	318,648	527,85	435,71	564,876	**2592,584**
22	Production costs	992,2	754,4	749,76	1210,95	961,125	1246,05	**5914,485**
23	Inventory costs	0	0	0	0	0	45,63	**45,63**
24	Transport costs	484	368	356,136	589,95	499,785	524,16	**2822,031**
25	Lost Sales costs	0	0	0	0	0	0	**0**

26	Total monthly costs	1899,7	1444,4	1424,544	2328,75	1896,62	2380,716	**11374,73**
27						TOTAL	PROFIT	**5.360.793**

Source: Authors

6. DISCUSION

Based on the data from Table 5, it is clear that even in turbulent business conditions, the supply chain can operate successfully and will make a profit in the amount of €5,360,793. It is an optimal solution that is 9.36% better than the empirically least favourable solution obtained when the function is solved by the minimum. The offered solution ensures production with minimal inventory within the supply chain and without the costs of lost sales. Operating a supply chain without the cost of lost sales means that all customer requests will be met on time. The total inventory costs will amount to €45,630, and that's only because the management decided to increase inventory for speculative reasons in order to respond more efficiently to the challenges of inflation. Otherwise, the supply chain would operate without inventory costs. Disruption in the supply chain affects the inventory management. For example, shortages of inventory versus surplus of inventory have different impact on the supply chain (Ozgur, Fedor, Michel, 2021). Shortages of inventory result in the costs of lost sales, dissatisfied customers, and loss of business reputation while the surplus of inventory results in higher costs, wasted resources, and lost profits. Building a more dynamic supply chain through diversifying suppliers and taking steps to identify local (near-shore) alternatives to current suppliers who might pose less risk could be the right solution.

Table 6 gives a comparative view of the operations of the optimized supply chain under conditions of dynamic and static stability.

Table 6 Comparison of operations of the optimized supply chain under conditions of dynamic and static stability

	Dynamic stability	Static stability	+/-	%
Optimal production	691	702	-11	-1,57
Total demand	676	702	-26	-3,70
Procurement costs	2592,584	2408,1	184,484	7,66
Production costs	5914,485	5499,5	414,985	7,55
Inventory costs	45,63	19,5	26,13	134,00
Transport costs	2822,031	2691,2	130,831	4,86
Lost Sales costs	0	0	0	0,00
Total costs	11374,73	10618,3	756,43	7,12
Total revenue	16735,52	16146	589,52	3,65

Profit	5360,793	5527,700	-166,907	-3,02

Source: Authors

Based on the data from Table 6, it is clear that disruptions in the supply chain resulted in 1) a decrease in demand, 2) a decrease in production, 3) an increase in costs in all categories, and 4) a decrease in profit. This finding is similar to the findings of Mishra, Singh. and Subramanian (2021) and Sharma and Kumar (2021) who recognize disruption in supply chains on three different sides; supply side, demand side, and logistical side. Supply chain product demand decreased by 26,000 thousand products while production decreased by 11,000 thousand products. The difference of 15,000 products is intended to increase inventory at the end of the six-month period for speculative reasons. Disruptions in the supply chains changed the inventory policy to combat extreme shocks (Raj et al., 2022). The total costs of the supply chain are higher by €756,430 or by 7.12%, which is the result of the increase in all prices due to inflation. According to the research conducted by The Economist Intelligence Unit (2021) disruptions have incurred substantial financial costs (averaging 6-10% of annual revenues). However, thanks to the timely increase in the selling prices of product A, the supply chain in conditions of dynamic stability achieved higher total revenues by €589,520 or by 3.65%. According to the research conducted by The Economist Intelligence Unit (2021), the disruption of the supply chain caused by COVID-19 hit the revenue between 6% and 20%. Due to the achievement of dynamic stability, the supply chain was able to consolidate and optimize it s operations and operate profitably, even in conditions of whirlwind changes in the environment (inflation, decrease in demand). The profit is only €166,907 or 3.02% less than in the conditions of static stability. One McKinsey study (2020) found that supply chain disruptions cost companies 42 % of one year's profits over the course of a decade. The set model offers numerous "what-if" answers. For example, if the supply chain had failed to raise the price of its product by 10% in the fourth month, the total revenue and total profit of the supply chain would have been lower by more than €860,000.

7. CONCLUSION

Supply chain disruptions are a „new normal in business for all supply chain active participants. Supply chains have to prepare for future "black swan" threats. Supply chain disruption has many negative consequences such as 1) a decrease in demand, 2) a decrease in production, 3) an increase in costs in all categories, and 4) a decrease in profit. To avoid negative consequences of disruptions future supply chains will need to be much more dynamic. The dynamic stability of the supply chain is based on its ability to anticipate, detect, diagnose, and monitor changes and activate appropriate mechanisms with the aim of protecting the supply chain from unwanted disruptions. Dynamic stability is the shield against disruption in the supply chain and the main factor in increasing the performance of all active participants in the supply chain.

In the presented example, despite the unfavourable conditions from the economic environment (high inflation, decrease in demand), thanks to the achievement of dynamic stability, the supply chain achieved a lower profit of only 3.02%, in contrast to the operation of the supply chain in conditions of static stability (unchanged business conditions). This result confirmed the hypothesis that supply chains can successfully manage unexpected changes in the business environment by achieving dynamic stability.

The research has some limitations because the proposed model does not directly include the disruptions in supply chains that produced new Western country policies that promote "friendshoring" of strategic industries. Future research should be directed to building a model that will enable the optimal restructuring of supply chains, shifting production away from geopolitical rivals to friendly powers. The new policy in the first plan put the place where the product is produced rather than profit.

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