An Extended Optimization Model on Supply Chain Resources Integration in 4PL

YAO Jianming
School of Business, Renmin University of China, P.R.China, 100872
jmyao@163.com

Abstract: Integrating the supply chain resources is an important way to improve the enterprises’ operational efficiency and effectiveness, but it is hard to do this because of the complexity of the resources. At present, the successful operation of the fourth party logistics (4PL) in practice gradually demonstrates that it is an effective mode to integrate the complicated resources of the supply chain efficiently and flexibly, but there are absent of the quantitative analysis theory and method of this new 4PL integration mode. Therefore, based on the related theoretical framework put forward by our early study, this paper present an extended integration decision optimization model which can give more accurate reflection on 4PL integration mode. By case test, the decision optimization model in this paper is reasonable and feasible. Finally, the related conclusions of this research are given.

Keywords: 4PL, Supply chain resources integration, An extended optimization model

1 Introduction

The supply chain resources integration process is generally enslaved to a paradox for a long time. This paradox is among “how to handle a reasonable level of customer service satisfaction, the resource integration costs and the operating profits of the integrated supply chain system”. Therefore, we must probe the way to effectively integrate, operate and monitor the complex resources of supply chain and to maximize the current and long-term benefits of the supply chain members. The operational essence and the core superiority of 4PL (the fourth party logistics) lie in its ability to integrate the supply chain resources. Through integrating the most high-quality supply chain resources (cooperators), flexibility of the supply chain will be get to a full extend. Therefore, customers will receive personalized, diversified integration solutions, and fast, high-quality and low-cost logistics services will be provided [1]. It is obvious that integration resources in 4PL mode can create favorable conditions to resolve this paradox. It will be gradually proved that the resources integration mode of 4PL has become the dominant direction of the logistics industry development either for theory or in practice [2~4].

However, it should be of great concern is that the rational and efficient supply chain resources integration by 4PL mode is a complex and systemic problem.

The initial concept of 4PL was put forward in Accenture’s reports in 1998. Thus many subsequent researches on 4PL were extensive discussion of this report. There are mainly two categories involved 4PL. One is in newspapers and magazines, mainly about the practical application of 4PL [5,6]. There existed some introductory and scholarly articles. Most of these articles focus on the qualitative introduction of the new concept of 4PL [2,3]. These literatures are rather abundant, involving the significance and advantages of 4PL compared with 3PL [7,8], definition of 4PL concept, feasibility and inevitability of 4PL development [9,10], characteristics and the operational patterns of 4PL [1,11,12] and so on.

Another part studies the operational problems under the guidance of 4PL by the introduction of quantitative methods. Such as the researches of the operational problems of the supply chain in 4PL mode [12] and the technical support of the 4PL used in the operation of the supply chain network [13] and so on. The results of such studies are less.

The existed 4PL researches have important reference value to set up basic operational mode framework and guide research direction in 4PL field. However, in present literatures, there have not
been systematic research theories or achievements on the supply chain resources integration by 4PL. In integration decision process, analyses and researches on relations among dominant factors and on connection between integration input and output are especially absent. If researches on 4PL have always rested on qualitative concept analyses and on operational pattern discussion, the expansion of 4PL in practical operation will be limited. Meanwhile, without reasonable quantitative mode of 4PL, the superiority of this operational mode can not be thoroughly reflected. So, the quantitative study tasks of 4PL integration are very necessary and urgent.

2 The Early Study Achievement

In our early study achievement (such as the reference [14]), we firstly analyzed the dominant factors of this integration decision process at operational level from the perspective of value increment theory and systemic integration principles based on 4PL integration framework. Then to direct the integration practice, we put forward an optimization mathematical model for this complex resources integration decision and discussed in reference [15]. However, the limitation of the model is that it only discussed three dominant factors. So, in order to extend the number of the dominant factors discussed, in this paper, we will setup an extended decision optimization model of the supply chain resources integration in 4PL to make the decision process of the integration optimization close to the practice.

3 An Extended Decision Optimization Model

3.1 Notation and related explanation

Based on opinions discussed above, we build an extended decision optimization model for 4PL resources integration. The notation of the model is shown in Table 1.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>$K$</td>
<td>Categories of required resources for 4PL integration aimed to some production or service activities in supply chain. The resources include existing individuals and new ones.</td>
</tr>
<tr>
<td>$k$</td>
<td>Index of individual category, $k = 1, 2, ..., K$</td>
</tr>
<tr>
<td>$L_k$</td>
<td>Number of individuals that will be integrated in the $k$th category</td>
</tr>
<tr>
<td>$i_k$</td>
<td>Index of individual, $i_k = 1, 2, ..., L_k$</td>
</tr>
<tr>
<td>$F$</td>
<td>Expected synthetic operational level of supply chain system after 4PL integration</td>
</tr>
<tr>
<td>$F_{\text{Hard},m}$</td>
<td>Expected operational levels of hard environmental factors after 4PL integration, $m = 1, 2, ..., M$</td>
</tr>
<tr>
<td>$F_{\text{Hard},n,i}$</td>
<td>Operational levels of hard environmental factors of $i_k$ before 4PL integration</td>
</tr>
<tr>
<td>$F'_{\text{Hard},n,i}$</td>
<td>Operational levels of hard environmental factors of $i_k$ after 4PL integration</td>
</tr>
<tr>
<td>$F_{\text{Soft},n,i}$</td>
<td>Operational levels of soft environmental factors of $i_k$ before 4PL integration</td>
</tr>
<tr>
<td>$F''_{\text{Soft},n,i}$</td>
<td>Operational levels of soft environmental factors of $i_k$ after 4PL integration</td>
</tr>
<tr>
<td>$\Delta F_{\text{Hard},n,i}$</td>
<td>Operational level improvement of dominant factor $m$ of individual $i_k$ in supply chain after 4PL integration. There is the relation: $\Delta F_{\text{Hard},n,i} = F'<em>{\text{Hard},n,i} - F</em>{\text{Hard},n,i}$</td>
</tr>
<tr>
<td>$\Delta F_{\text{Soft},n,i}$</td>
<td>Operational level improvement of dominant factor $n$ of individual $i_k$ in supply chain after 4PL integration. There is the relation: $\Delta F_{\text{Soft},n,i} = F''<em>{\text{Soft},n,i} - F</em>{\text{Soft},n,i}$</td>
</tr>
<tr>
<td>$C_{\text{Hard},i}$</td>
<td>Total costs put into individual $i_k$ to improve its operational levels of hard environmental factors</td>
</tr>
<tr>
<td>$C_{\text{Soft},i}$</td>
<td>Total costs put into individual $i_k$ to improve its operational levels of soft environmental factors</td>
</tr>
<tr>
<td>$\Delta C_{\text{Hard},n,i}$</td>
<td>Costs put into individual $i_k$ to improve the operational level of hard environmental factor $m$</td>
</tr>
<tr>
<td>$\Delta C_{\text{Soft},n,i}$</td>
<td>Costs put into individual $i_k$ to improve the operational level of soft environmental factor $n$</td>
</tr>
</tbody>
</table>
Operational quality provided by individual $i_k$

Standard quality demand for production or service activities of category $k$

Capacity of production or service activities provided by individual $i_k$

Capacity demand for production or service activities of category $k$

Starting time of production or service activities provided by individual $i_k$

Ending time of production or service activities provided by individual $i_k$

Starting time demand for production or service activities of category $k$

Ending time demand for production or service activities of category $k$

Tolerant value of starting time about production or service activities of category $k$

Tolerant value of ending time about production or service activities of category $k$

Total tolerant time value of production or service activities of category $k$ with relation:

Coefficient to unify the units of cost and tolerant time value

If individual $i_k$ selected to 4PL integration, then $\delta_k = 1$, otherwise $\delta_k = 0$.

From reference [14] we can learn that in the 4PL integration, the costs put into dominant factors will affect the factor itself, the other factors in the same environment and in different environment. Here, we should define the effect coefficients of these relations as shown in Table 2. The effect relations in Table 2 follow clockwise principle. For example, the effect relation coefficient of the costs put into factor $SF_1$ (e.g. management style) will improve the operational level of $SF_2$ (e.g. organizational structure) which is denoted by $H_{12}$; the effect relation coefficient of the costs put into $SF_2$ (e.g. organizational structure) will promote the operational level of $HF_2$ (e.g. capital flow) which is denoted by $R_{22}$. $S$ and $V$ denote the relations between the costs put into factors and their operational levels improved by the costs.

Table 2  Affect Relation Coefficients of the Factors in 4PL Integration

<table>
<thead>
<tr>
<th>Hard environmental factors</th>
<th>Soft environmental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{11}$ $Y_{12}$ $Y_{13}$ ... $Y_{1n}$</td>
<td>$SF_1$ $H_{12}$ $H_{13}$ ... $H_{1n}$</td>
</tr>
<tr>
<td>$Y_{21}$ $Y_{22}$ $Y_{23}$ ... $Y_{2n}$</td>
<td>$H_{21}$ $SF_2$ $H_{23}$ ... $H_{2n}$</td>
</tr>
<tr>
<td>$Y_{31}$ $Y_{32}$ $Y_{33}$ ... $Y_{3n}$</td>
<td>$H_{31}$ $H_{32}$ $SF_3$ ... $H_{3n}$</td>
</tr>
<tr>
<td>... ... ... ... ...</td>
<td>... ... ... ... ...</td>
</tr>
<tr>
<td>$Y_{m1}$ $Y_{m2}$ $Y_{m3}$ ... $Y_{mn}$</td>
<td>$H_{m1}$ $H_{m2}$ $H_{m3}$ ... $SF_m$</td>
</tr>
<tr>
<td>$G_{11}$ $G_{12}$ $G_{13}$ ... $G_{1n}$</td>
<td>$R_{11}$ $R_{21}$ $R_{31}$ ... $R_{1n}$</td>
</tr>
<tr>
<td>$G_{21}$ $HF_1$ $G_{23}$ ... $G_{2n}$</td>
<td>$R_{12}$ $R_{22}$ $R_{32}$ ... $R_{2n}$</td>
</tr>
<tr>
<td>$G_{31}$ $G_{32}$ $HF_1$ ... $G_{3n}$</td>
<td>$R_{13}$ $R_{23}$ $R_{33}$ ... $R_{3n}$</td>
</tr>
<tr>
<td>... ... ... ... ...</td>
<td>... ... ... ... ...</td>
</tr>
<tr>
<td>$G_{mn1}$ $G_{mn2}$ $G_{mn3}$ ... $HF_m$</td>
<td>$R_{mn1}$ $R_{mn2}$ $R_{mn3}$ ... $R_{mn}$</td>
</tr>
<tr>
<td>$S_{11}$ $S_{22}$ $S_{33}$ ... $S_{nn}$</td>
<td>$V_{11}$ $V_{22}$ $V_{33}$ ... $V_{nn}$</td>
</tr>
</tbody>
</table>
3.2 Optimization model

An extended decision optimization model for the supply chain resources integration in 4PL mode is as follows.

Objective function:

\[
\begin{align*}
\min Z &= \min C_{\text{Total}} + \beta \min \theta_{\text{total}} = \sum_{k=1}^{K} \sum_{i=1}^{I} \left( \frac{\sum_{j=1}^{J} \left( C_{\text{Soft,}i,j} + C_{\text{Hard,}i,j} \right) + \beta \theta_{i,j} \delta_{i,j} \right) \\
&= \sum_{k=1}^{K} \sum_{i=1}^{I} \left( \frac{\sum_{m=1}^{M} \Delta C_{\text{Hard,}i,m,j} + \sum_{n=1}^{N} \Delta C_{\text{Soft,}i,n,j} \right) + \beta \left( \theta_{\text{Sat,}i,j} + \theta_{\text{End,}i,j} \right) \delta_{i,j} \\
&= \sum_{k=1}^{K} \sum_{i=1}^{I} \left( \frac{\sum_{m=1}^{M} \Delta C_{\text{Hard,}i,m,j} + \sum_{n=1}^{N} \Delta C_{\text{Soft,}i,n,j} \right) + \beta \left( \theta_{\text{Sat,}i,j} + \theta_{\text{End,}i,j} \right) \delta_{i,j} \\
&= \sum_{k=1}^{K} \sum_{i=1}^{I} \left( \sum_{m=1}^{M} \Delta C_{\text{Hard,}i,m,j} + \sum_{n=1}^{N} \Delta C_{\text{Soft,}i,n,j} \right) + \beta \left( \theta_{\text{Sat,}i,j} + \theta_{\text{End,}i,j} \right) \delta_{i,j}.
\end{align*}
\]  

Subject to:

\[
\begin{align*}
\left[ \Delta F_{\text{Hard,}1,i,j} \right] & = \left[ R_{i1} R_{i2} R_{i3} \ldots R_{iJ} \right] \Delta C_{\text{Soft,}1,i,j} + \left[ S_{i1} S_{i2} S_{i3} \ldots S_{iM} \right] \Delta C_{\text{Hard,}1,i,j} \\
\left[ \Delta F_{\text{Hard,}2,i,j} \right] & = \ldots \\
\left[ \Delta F_{\text{Hard,}n,i,j} \right] & = \left[ R_{i1} R_{i2} R_{i3} \ldots R_{iJ} \right] \Delta C_{\text{Soft,}n,i,j} + \left[ S_{i1} S_{i2} S_{i3} \ldots S_{iM} \right] \Delta C_{\text{Hard,}n,i,j} \\
\left[ \Delta F_{\text{Soft,}1,i,j} \right] & = \left[ Y_{i1} Y_{i2} Y_{i3} \ldots Y_{iM} \right] \Delta C_{\text{Hard,}1,i,j} + \left[ H_{i1} H_{i2} H_{i3} \ldots H_{iM} \right] \Delta C_{\text{Soft,}1,i,j} \\
\left[ \Delta F_{\text{Soft,}2,i,j} \right] & = \ldots \\
\left[ \Delta F_{\text{Soft,}n,i,j} \right] & = \left[ Y_{i1} Y_{i2} Y_{i3} \ldots Y_{iM} \right] \Delta C_{\text{Hard,}n,i,j} + \left[ H_{i1} H_{i2} H_{i3} \ldots H_{iM} \right] \Delta C_{\text{Soft,}n,i,j} \\
F_{\text{Hard},i,j}^* & \geq \frac{F_{\text{Hard},i,j}}{m} = 1,2,\ldots,M \\
F_{\text{Soft},i,j}^* & \geq \frac{F_{\text{Soft},i,j}}{n} = 1,2,\ldots,N \\
T_{\text{Sat},i,j} - T_{\text{Sat},i,j}^* & \leq \theta_{\text{Sat},i,j} \\
T_{\text{End},i,j} - T_{\text{End},i,j}^* & \leq \theta_{\text{End},i,j} \\
Q_{i,j} & \geq Q_{i,j}^* \\
\sum_{i=1}^{K} A_{i,j} \delta_{i,j} & \geq A_{k}^*
\end{align*}
\]  

In the model, equation (1) is multi-objective function aims to minimize the integration costs of the supply chain system and the tolerant values of time limit for production or service activities. Equation (2) is the relations between the improved operational levels of the hard environmental factors and the integration costs put into each factors; equation (3) is the constraint of the demanded operational levels of the hard environmental factors; equation (4) is the relations between the improved operational levels of the soft environmental factors and the integration costs put into; equation (5) is the constraint of the demanded operational levels of system’s soft environmental factors; equation (6) and (7) are timeliness constraints of the production or service activities provided by system’s individuals; equation (8) and (9) are respectively the quality constraint and capability constraint of the production or service activities provided by system’s individuals.

We use an improved ant algorithm [16~18] to solve the above model. We also validate the reasonability and feasibility of the model in the optimization decision of the supply chain resources integration in 4PL through a case study and simulation.
4 Conclusions

This paper established an extended resources integration decision optimization mathematical model based on the early analyses of the dominant factors and on the original decision optimization model of the supply chain resources integration in 4PL. By the example test, the model not only reflect the complicated basic characters of the supply chain resources integrating process but also merge into the solution methods of several important relations in the 4PL integration process. The model is also the transition bridge from the integration decision process to the practice.

In future study about this thesis, we should firstly give more stress on the dominant factors which in reality play a decisive role in the 4PL integration decision and in the building of the optimization model. Because they are numerous and complex and it is needed to give the in-depth, detailed and refined analysis on them. For the integration mode of 4PL is a leading edge operational mode in the supply chain management field, in future study, we should focus on the different relations reflected in the optimization model, especially the relations about the different production or service industries. At the same time, it needs more in-depth analysis about the decision optimization model building and about the solutions of the model in order to guide practice with better integration strategy and exploit the 4PL’s advantages in the supply chain resource integration to the full.

Reference