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Modelling the 3PL Service Chain in Steel Bar Logistics

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The aim of the paper is to present a conceptual exploration on how a newly emerged distribution service business in China is developed, interpreted and modelled. The changes in logistics process and structure were primarily driven by not only the higher returns on investment to the participating members individually, but also by that of the total supply chain. The study draws on a recent case from a fast expanding 3PL company in China and frames the case with a conceptual flow-model and interprets it mathematically by using a linear bi-level programming algorism. The emerged steel bar logistics service model studied here represents a new business evolution in the 3PL service industry in China. The application of bi-level programming algorithm in assessing returns on investment and the total supply chain value has been original.

Keywords: Supply chain configuration**,** Logistics service, Distribution network

1. Introduction

Recent years have witnessed the spontaneous growth of the 3PLs in China capturing more and more customer oriented services for their client companies (Wang *et al*., 2008, Zhou *et al*, 2008). In particular, for the construction industry the standardised steel bar processing is now largely carried out by the factories that are vertically integrated into the 3PL's distribution channels. Such expansion of services for their client companies have consequently driven more 3PLs to become specialised niche market players, thus demarcated their turfs for competition, and ultimately changed the competitive landscape of 3PLs in China. The main motivation of this study is to re-think the strategic dilemma on whether to become the generic service provider or to transform into a specialist player by evaluating the total supply chain values and returns on investment.

Specifically we looked into the case of a leading 3PL that specialising in steel bar distribution in northern part of China. The steel bar components fabrication now taken on by the 3PL are called *Commercial Steel Bar Product* (CSBP). The processes to produce the CSBP by the 3PL to the specific customer orders of the construction companies are now centralised from a supply chain perspective. This reconfiguration of the supply chain has been a major development that may have profound implications to the overall value-adding and the returns on investment for the whole supply chain.

The problem is that it is not so clear what are the key drivers and trigging factors for the new model to emerge; to academics, nor is it a theoretically indorsed practice that may have a generic applicability to other industrial sectors. Thus, the purpose of this paper is to give an expository account of what has been happening to the leading 3PL provider in question, and explore the conceptual understanding on the

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value proposition offered by the re-configuration of the 3PL; and to attempt a conceptual modelling of the ROI of the emerging business model in hope to theorise some of its economic rationales behind it.

The uniqueness of this study is that a real world case from Bo-Yuan Logistics Company is presented and analysed with the diagramming flow-models; and the linear bi-level programming has also been exercised to reveal the ROI for the individual participating members of the supply chain as well as the ROI for supply chain as a whole.

The rest of the paper is arranged as follows. The next section gives a quick review of some of the existing concepts in the literatures. Then, a recent steel bar 3PL case is presented and discussed, based on which two flow-models of the steel bar supply chain are created to illustrate the key structure reconfiguration. Based on the model, the linear bi-level programming algorism (Ben-Ayed, O.,1993) is applied to formulate and optimise the ROI for the participating companies. Finally conclusions are drawn and research limitation remarked.

2. Literature Review

Over the last 20 years global business giants have stepped into China's traditionally closed domestic logistics market and has posed some serious threats to the newly emerged indigenous 3PL industries (Hong and Liu 2007; Lai *et al*., 2007). Consequently, many Chinese logistics companies become more actively engaged in the strategic redeployment and operational up-grading in order to survive the competition (Wang *et al*., 2008). The competitive frontier of 3PLs in China continues to be propelled from the cost efficiency focused operations to customer oriented service offerings; from the basic general transport provision to specialised one-stop package provider (Lai et al., 2007). There is a considerable body of literature to support that the ultimate competitiveness of 3PLs in China lies in the effective management of service innovation and market agility (Grawe, 2009; Hunt, 2002; Lippert and Forman, 2006). Customer oriented 3PL firms can compete much more effectively and can gain growing market share by providing wide range of specialised service-related activities, which may or may not seem to fall within their traditional business scope (Panayides, 2007; Knemeyer and Murphy, 2005).

The segmented logistics markets in China has also given rise to the demand from the buyers for more specialised core competencies, which may define the competitive edges for the 3PL providers (Sink et al., 1996). In the same vein, the changing market requirements also force 3PLs to reconfigure their supply chain (Abrahamson and Brege, 1997). The reconfiguration may have various profound impacts on the supply chain behaviour and performances. The functional based firm may become more a process-oriented organisation, requiring complete redesign of information systems. The dyadic relationship with supplier and client companies will almost certainly require different postures as a consequence. The capital investment and asset management may take on very different strategies.

Whatever the measure, ultimately the success of a 3PL provider lies in its value creation from the total value chain perspective (Christopher, 1998). Thus it is perhaps the most important concept of supply chain development that only the overall supply chain success accounts for the success of the participative members.

Looking at the value adding from another aspect of changing competitive environments, Webb and Gile (2001) argued that changing customer requirements would also impact on the value adding aspects of the supply chain participants. This was precisely what has happened in the case of Bo-Yuan Logistics Company.

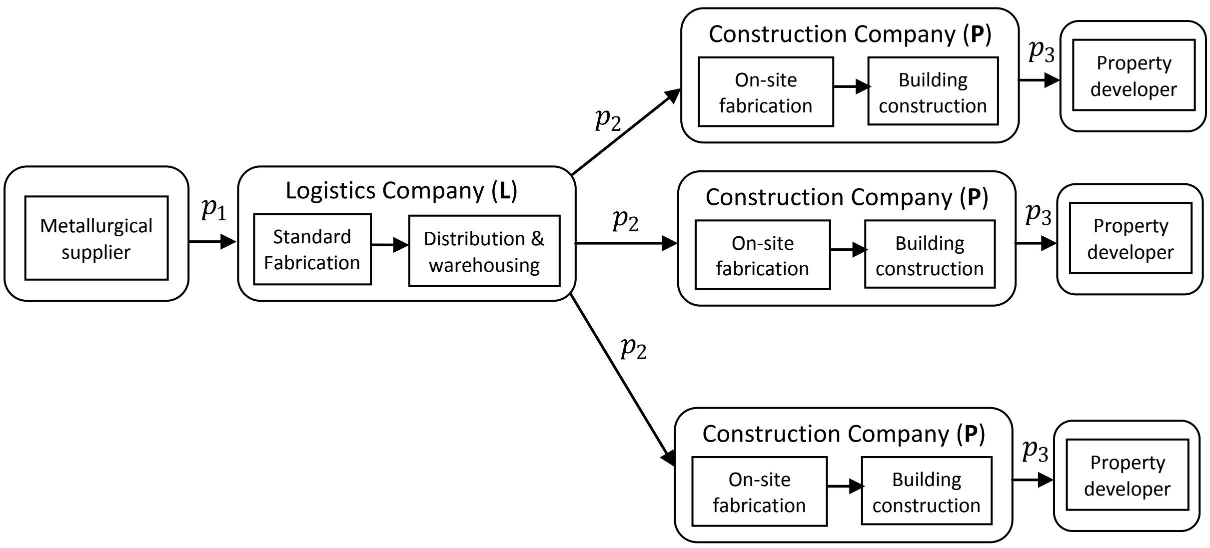
However, from the literatures we reviewed, none has addressed the changing business models in China's steel bar logistics business, nor attempted the analysis of the supply chain structural optimisation by application of bi-level programming algorithm.

3. Case Analysis

Bo-Yuan Logistics Company (BYL) is one of the China's leading 3PL service providers specializing in steel bar components fabrication, warehousing and distribution. It was established on January 1st, 2001 in *Jinan* – the capital city of Shandong province one of the fastest growing regions in China. At the beginning, the purpose of BYL is to provide high quality customer-oriented 3PL services for large construction companies. Steel bar processing, storage, transport and distribution were chosen as the main line of business.

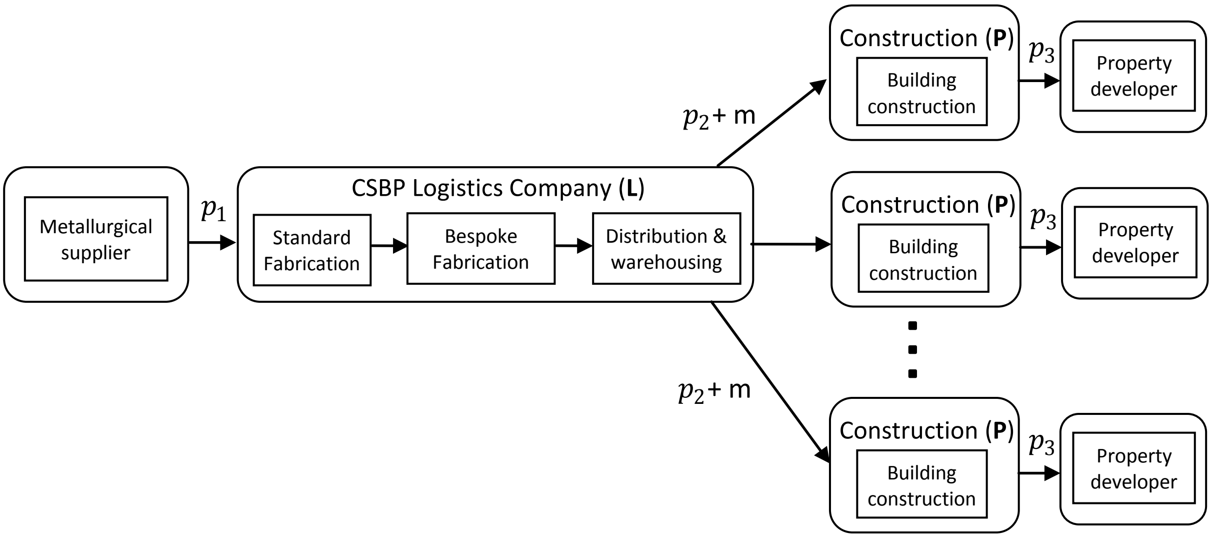
To meet the demand from the fast growing market and face up to the fierce competition in the steel bar product design and fabrication market, BYL has been pursuing religiously the innovative ways to better serve its customers and grow its customer base. As one of the first major steps, BYL vertically integrated the standard steel bar fabrication process and added in the packaging and warehousing on top of the usual transportation services. This business model has lead to a significant cost saving for the client companies. This operating model (referred to as model A below) was achieved at around 2005 and can be illustrated by figure 1.

Figure 1: The early Steel Bar Supply chain model — the Model A



The model A represents an evolved 3PL operation and structure. The arrows represent the material flows and the p_i is the transactional value proposition (unit prices). This model reveals one critical factor that the 3PL company has now taken on the extended but centralized service role to furnish a large client base. It also revealed that whilst the global steel producing companies are increasingly consolidated, the property developers on the other end of the supply chain tends to be more divers and proliferated due to the fast growing nature of the market conditions in China.

Figure 2: The emerging Steel Bar Supply chain model — the Model B



By 2008, BYL executives took a further major and possibly even a risky move to vertically integrate the steel bar components fabrication into its extended business scope, resulting in a further re-configuration of the steel bar supply chain. It was risky because in China's steel bar industry this was not a done-thing. BYL invested heavily in the purchasing of some of the state-of-the-art equipments and created a process that can fabricate steel bar components efficiently at an unprecedented high quality standard. Attractive price and high standard customer services were also proffered to the client companies in order to break the initial resistance. This model (model B as below) can be illustrated in figure 2.

In this operating model, the 3PL company has taken on yet another steel bar fabrication function and centralized it for the entire cast of construction client base. For the construction company, the steel bar components became the purchased commercial products instead of in-house made artifacts. The construction companies take charge of the testing, installation and adjusting the steel bar components for their specific needs. Thus the steel bar components produced in Model B is defined as a service product including prefabricating steel bar components, and the storage and distribution of them. In this way, the steel bar components can be customized and transported as the regular commodities. By 2009, the success of BYL Company's CSBP model was beyond the shadow of doubt, showing significant profit growth on top of the more than doubled revenue stream. It became an undisputed industrial leader in the steel bar industry in China.

Based on the case study we arrive at a research hypothesis: The steel bar 3PL value chain can be optimized by centralizing the CSBP fabrication – a supply chain reconfiguration process; but the reconfiguration may not guarantee it.

4. Modelling Methodology

Assume the participating member of the supply chain is $i: i \in \{L, P\}$, L represents the 3PL logistics company (or the *distributor*) and P represents the construction companies (or the *constructor*) as shown in figure 2. The decision space for choosing or preferring alternative supply chain models is S_i: the logistics company's decision space therefore is $S_L = \{Model\ A, Model\ B\}$, and the construction company's decision space is $S_P = \{Model\ A, Model\ B\}$. The gains function $U_{i:}\ U_L = \{R_L^A, R_L^B\}$; $U_P = \{R_P^A, R_P^B\}$ represents either companies' gains under either model A or B, where R_i is defined here as the rate of return as:

$$R_i = \frac{Gain\ from\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment}$$

This return on investment (ROI) is a broad and generic definition for the purpose of assessing company's overall gain rather than a strictly technical definition in financial investment context. We assume that there are n construction companies in the supply chain and they all require d tonnes of steel bars each for the whole contracted period. Their customers are the *property developers*. We also assume:

p_2 – purchasing price of standard steel bar from the distributor (in model A), in ¥/tonne.
m – price mark-up (increase) for the bespoke steel bar component provided by the distributor (in model B instead of making and selling normal standard steel bars), in ¥/tonne.
v_f – cost of fabricating the steel bar components on-site of the each construction site by the usually low technology labour intensive production processes, in ¥/tonne.
v_t – cost of construction in which 1 tonne of steel bar components is used, in ¥/tonne.
p_3 – revenue received from the constructor's customer – the property developer, in ¥ for the whole project period.
d – total tonnage required by each construction company to complete the contract within the defined period, in tonne/project period.
n – total number of the construction companies in the supply chain as the customers of the distributor.
p_1 – price of steel from the metallurgical supplier, in £/tonne.
v_s – cost of manufacturing every tonne of standard steel bars from steel, in ¥/tonne
γ – efficiency factor (0< γ <1), and the γv_f is the unit cost of fabricating 1 tonne of steel bars into steel bar components by the distributor. The γ reflects how much lower it may be.
E – Depreciation cost of the investment of the high tech automated steel bar fabrication machine in ¥/project period.

For the model A configuration, the *investment return* for both participating members (*L* and *P*) can be expressed as:

$$R_L^A = \frac{ndp_2 - (ndp_1 + ndv_s)}{(ndp_1 + ndv_s)} = \frac{p_2}{p_1 + v_s} - 1 \tag{1}$$

(2)

$$R_P^A = \frac{dp_3 - (dp_2 + dv_f + dv_t)}{dp_2 + dv_f + dv_t} = \frac{p_3}{p_2 + v_f + v_t} - 1$$

And similarly, for the model B configuration the *investment return* for both participating members can be expressed as:

$$R_L^B = \frac{nd(p_2 + m) - \left[ndp_1 + nd\left(v_s + \gamma v_f\right) + E\right]}{ndp_1 + nd\left(v_s + \gamma v_f\right) + E} = \frac{p_2 + m}{p_1 + v_s + \gamma v_f + \frac{E}{nd}} - 1 \quad (3)$$

$$R_P^B = \frac{dp_3 - [d(p_2 + m) + dv_t]}{d(p_2 + m) + dv_t} = \frac{p_3}{p_2 + m + v_t} - 1 \quad (4)$$

In order to simplify the analysis and focus on the key issues, we further assume that there are only two controllable variables m and γ in the equations and all the rest are constant. The mark-up m is one of the critical control variables because it balances the returns between the distributor and the constructors. The γ is also critical because it represents how much more efficient or lower cost the centralised fabrication process can offer than the ones on-site. The return functions are formulated from the individual company's (L or P) perspective. The objective is to determine that in which ways, model A or model B, it can maximise its return on investment by adjusting the two controllable variables m and γ. From equation (1) to (4), for company *P*, the return functions R_P^A and R_P^B only involve one variable *m* but not γ. Thus the objective function will be on maximising the R_P by controlling over the variable *m*. The variable *m* represents the price mark-up for *P* from *L*, if *P* chooses to outsource the steel bar components fabrication to the distributor *L*, i.e. prefer model B configuration for the supply chain. Clearly *P* will have significant power in negotiation on the possible price mark-up *m*, i.e. it is certainly controllable by *P*. Its objective function therefore is defined as:

$$\max_m R_P(m) = \beta R_P^B + (1 - \beta) R_P^A$$

Where $\beta \in \{0.1\}$

Now for the company *L*, its return function involves both m and γ. The key management control is the variable γ, as it represents how much more efficient or lower cost it can achieve in carrying out the fabrication of components for the customer as part of the logistics services. The consolidated volume and hi-tech automated machineries that *L* invested will certainly help to significantly improve the cost efficiency in comparison with the on-site labour intensive fabrication processes. Nevertheless, how well *L* can achieve its maximum return will also partially depend on the variable m to which the company *P* has a good influence. Thus the objective function for *L* is at a level above the one where *P* optimises its return functions and adjusts its only controllable variable m.

$$\max_{\gamma} R_L(\gamma, m) = \alpha R_L^B + (1 - \alpha) R_L^A$$

$Where\ \alpha \in \{0.1\}$

Therefore, the problem for both companies *L* and *P* in the same supply chain to maximise their individual returns is better to be modelled as a linear *bi-level programming* problem, where the main objective function being the one to achieve highest return for L, and the decision would be constrained by the decisions in P who is also seeking the highest return in its given conditions. Thus we have:

$$\max_{\gamma} R_L(\gamma, m) = \alpha R_L^B + (1-\alpha) R_L^A \qquad (5)$$
$$s.t. \begin{cases} \max_{m} R_P(m) = \beta R_P^B + (1-\beta) R_P^A \\ m \geq 0 \\ 0 < \gamma \leq 1 \\ \alpha, \beta \in \{0.1\} \end{cases}$$

Here, R_L is the up level programming objective function for the distributor L, and R_P is the lower level programming objective function for the construction company P. Now we can proceed to solve this bi-level programming problem. In fact, both objective functions are designed in the form of achieving the maximum return through choices. It all depends on which model (A or B) offers greater returns under the given ranges of the control variables. So the first step is to make clear how the ranges of the control variables correspond to the relative returns from either models.

For the construction company P:

If $R_P^B \geq R_P^A$, from (2) and (4) we have: $m \leq v_f$.
Similarly if $R_P^B < R_P^A$, from (2) and (4) we have: $m > v_f$.

For the distribution company L:

If $R_L^B \geq R_L^A$, from (1) and (3) we have:

$$\frac{p_2}{p_1 + v_s} - 1 \geq \frac{p_2 + m}{p_1 + v_s + \gamma v_f + \frac{E}{nd}} - 1$$

thus:

$$\gamma \leq \frac{1}{v_f}\left[\left(1 + \frac{m}{p_2}\right)(p_1 + v_s) - \left(p_1 + v_s + \frac{E}{nd}\right)\right] \qquad (6)$$

Conversely, if $R_L^B < R_L^A$, we have:

$$\gamma > \frac{1}{v_f}\left[\left(1 + \frac{m}{p_2}\right)(p_1 + v_s) - \left(p_1 + v_s + \frac{E}{nd}\right)\right] \qquad (7)$$

Combining all these ranges, a four quadrants variable space is defined as shown in figure 3. Corresponding to the ranges/quadrants, there come the four possible results of the maximum returns on investment as the solutions to the bi-level programming problem.

(1) In quadrant one, where $m \leq v_f$ and

$$\gamma \leq \frac{1}{v_f}\left[\left(1 + \frac{m}{p_2}\right)(p_1 + v_s) - \left(p_1 + v_s + \frac{E}{nd}\right)\right]$$

we have $R_P^B \geq R_P^A$ and $R_L^B \geq R_L^A$, from the objective function (5): $\alpha = \beta = 1$, thus $\max_m R_P = R_P^B$, and $\max_\gamma R_L = R_L^B$. The explanation of the corresponding scenario of this control choice is that when the mark-up m and the efficiency γ are controlled within the afore mentioned range (the desired range), then both the distributor and the constructors will choose the model B supply chain configuration, which is relationship based and much more integrated since it involves supplier and buyer working together to achieve the bespoke fabrication and services. In fact, the BYL case discussed above demonstrates precisely this scenario.

(2) In quadrant two where $m \leq v_f$ and

$$\gamma > \frac{1}{v_f}\left[\left(1+\frac{m}{p_2}\right)(p_1+v_s) - \left(p_1+v_s+\frac{E}{nd}\right)\right]$$

We have $R_P^B \geq R_P^A$ and $R_L^B < R_L^A$, from the objective functions we have $\alpha = 0,\ \beta = 1$, thus $\max_m R_P = R_P^B$, and $\max_\gamma R_L = R_L^A$. The explanation of the corresponding scenario of this control choice is that the constructors see the higher return by moving towards the model B operation, but the gain on economy of scope and productivity for the distributor is just too small and its return on the investment would be even lower in model B than in model A. This situation occurs when the distributor fails to identify the technology and process that secure the productivity in fabrication of the steel bar components.

(3) In quadrant three where $m > v_f$ and

$$\gamma \leq \frac{1}{v_f}\left[\left(1+\frac{m}{p_2}\right)(p_1+v_s) - \left(p_1+v_s+\frac{E}{nd}\right)\right]$$

We have $R_P^B < R_P^A$ and $R_L^B \geq R_L^A$, from the objective functions we have $\alpha = 1,\ \beta = 0$, thus $\max_m R_P = R_P^A$, and $\max_\gamma R_L = R_L^B$. The corresponding scenario of this control choice is that the constructor sees no incentives to outsource the fabrication business to the distributor because the mark-up by the distributor for the steel bar components is too high. The problem with this scenario is that the appropriate technology and process have been identified to achieve a much higher productivity and economy of scope, but the distributor failed to share this efficiency saving through an appropriate mark-up price on the steel bar components.

(4) In quadrant four where $m > v_f$ and

$$\gamma > \frac{1}{v_f}\left[\left(1+\frac{m}{p_2}\right)(p_1+v_s) - \left(p_1+v_s+\frac{E}{nd}\right)\right]$$

We have $R_P^B < R_P^A$ and $R_L^B < R_L^A$, from the objective functions we have $\alpha = \beta = 0$, thus $\max_m R_P = R_P^A$, and $\max_\gamma R_L = R_L^A$. The explanation of the corresponding scenario of this control choice is that when the mark-up m and the economy of scope γ are outside of the desired range, then both the distributor and the construction company would rather choose to stay in their traditional model A position, which has the transaction based relationship and less integrated supply chain development.

Figure 3: A summary of alternative supply chain configurations and their basic conditions.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Control Over γ</td></tr>
<tr><td colspan="2">$\gamma \le \frac{1}{v_f}\left[\left(1+\frac{m}{p_2}\right)(p_1+v_s)-\left(p_1+v_s+\frac{E}{nd}\right)\right]$</td><td colspan="2">$\gamma > \frac{1}{v_f}\left[\left(1+\frac{m}{p_2}\right)(p_1+v_s)-\left(p_1+v_s+\frac{E}{nd}\right)\right]$</td></tr>
<tr><td rowspan="4">Control over m</td><td rowspan="2">$m \le v_f$</td><td colspan="2">Model B
(Relationship based model)</td><td colspan="2">Inconclusive</td></tr>
<tr><td>$R_P^B \ge R_P^A$
$\max_m R_P = R_P^B$</td><td>$R_L^B \ge R_L^A$
$\max_\gamma R_L = R_L^B$</td><td>$R_P^B \ge R_P^A$
$\max_m R_P = R_P^B$</td><td>$R_L^B < R_L^A$
$\max_\gamma R_L = R_L^A$</td></tr>
<tr><td rowspan="2">$m > v_f$</td><td colspan="2">Inconclusive</td><td colspan="2">Model A
(Transaction based model)</td></tr>
<tr><td>$R_P^B < R_P^A$
$\max_m R_P = R_P^A$</td><td>$R_L^B \ge R_L^A$
$\max_\gamma R_L = R_L^B$</td><td>$R_P^B < R_P^A$
$\max_m R_P = R_P^A$</td><td>$R_L^B < R_L^A$
$\max_\gamma R_L = R_L^A$</td></tr>
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5. A Value Chain Perspective

Above analysis, however, is taken from a narrow perspective of the individual participating member of the supply chain, i.e. considering the return on investment from the individual company's perspective. A more fundamental question would be: which model provides higher returns for the whole supply chain? To this end, we need to re-create the returns on investment model from both the distributor and the constructors' perspective — the ROI model for the supply chain:

For the Model-A configuration:

$$R_{L+P}^A = \frac{ndp_3}{ndp_1 + ndv_s + nd(v_f + v_t)} - 1 = \frac{p_3}{p_1 + v_s + v_f + v_t} - 1$$

And for the Model-B configuration:

$$R_{L+P}^B = \frac{ndp_3}{ndp_1 + nd\left(v_s + \gamma v_f\right) + E + ndv_t} - 1 = \frac{p_3}{p_1 + v_s + \gamma v_f + \frac{E}{nd} + v_t} - 1$$

And the objective function becomes:

$$\max_\gamma R_{L+P} = \alpha R_{L+P}^B + (1-\alpha) R_{L+P}^A$$

$$s.t. \begin{cases} n, d \in integer, > 0 \\ 1 \ge \gamma \ge 0 \\ \alpha \in \{0.1\} \end{cases}$$

If $R_{L+P}^B \ge R_{L+P}^A$, then

$$\frac{p_3}{p_1 + v_s + \gamma v_f + \frac{E}{nd} + v_t} - 1 \geq \frac{p_3}{p_1 + v_s + v_f + v_t} - 1$$

Solve this equation we have:

$$\frac{E}{ndv_f} \leq \ (1 - \gamma)$$

Thus we arrive at a total supply chain value adding condition:

$$E \ \leq \ ndv_f \ (1 - \gamma) \tag{8}$$

This result tells us that at a given efficiency savings γ of model B configuration, if the Model-B is to have higher return on investment for both $L\ and\ P$, then the investment in the distributor should not exceed the value of $ndv_f\ (1 - \gamma)$ — a fraction of the total cost of fabrication of all the participating construction companies (n companies) put together. Apparently the lower the E, the better the total supply chain value adding.

This result shows that if the investment and the cost of deploying the new equipment and the centralised fabrication process by the distributor is greater than the cost of on-site fabrication put together, or if the efficiency gain is not high enough, then the overall supply chain wide return on investment in Model-B will not be attractive. Thus strategically it would not be justifiable to attempt the Model-B configuration.

6. Conclusions

This research demonstrated that the fast development and expansion in China's steel bar 3PL businesses exhibited some innovative best-practices in its unique economical, cultural and geo-political environment. The BYL case study and the related conceptual exploration shows that the trends and the behaviour of the steel bar supply chain in China is in broad agreement with the key known principals of supply chain development. However it is informative and revealing that the indigenous 3PL companies in China's steel bar industry have now embarked on a possibly irreversible journey to transform the traditional logistics business operations into a manufacturing and service integrated offering that the country has never seen before.

The modelling and analysis of the steel bar supply chain appears to be a very useful exercise in that it stretches our conceptual understanding further. The structures of the supply chain before and after the re-configuration have been flow-mapped by the model A and model B (as shown in figure 1, 2) Based on the models, attempts have been made to rationalise the re-configuration of the supply chain through an analytical approach rather than a narrative one.

The analysis reveals that the transition from Model A to Model B as it happened to BYL cannot be taken for granted. It depends very much on whether or not certain critical conditions are met. Thus the original hypothesis has been tested positive. Those conditions are largely controllable through some management parameters or variables. Only when the control variables fall within certain ranges (quadrant 1, in figure 3) can the Model-B supply chain be possibly achieved. Specifically, when the centralised components fabrication is a lot more efficient to be carried out by the distributor than by the on-site fabrications in the construction companies, and when the price mark-up for the completed bespoke components is less than the cost of the on-site fabrication cost, then both member of the supply chain would be driven toward the model B configuration. The same analytical approach is also applied to the supply chain's total return on investment. This analysis resulted in a strategic tool that can help executives to make sensible assessment on whether the conditions are ripe for a shift from Model-A to Model-B configuration. The tool can serve as a practical decision support to the supply chain and logistics managers.

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