SUPPLY CHAIN , COLLABORATIVE DESIGN & MANUFACTURING

- Once a firm has developed advanced supply chain management (ASCM) relationships on both the upstream (with key suppliers) and downstream (with key distributors and customers) sides of its supply chain network, it is in a strong position to begin working collaboratively with key business partners on new design and manufacturing techniques.
- The internal house will be in order and experiments with external partners should be showing the value of advanced networking with trusted allies.
- Improved manufacturing techniques are also part of the potential from this part of ASCM.

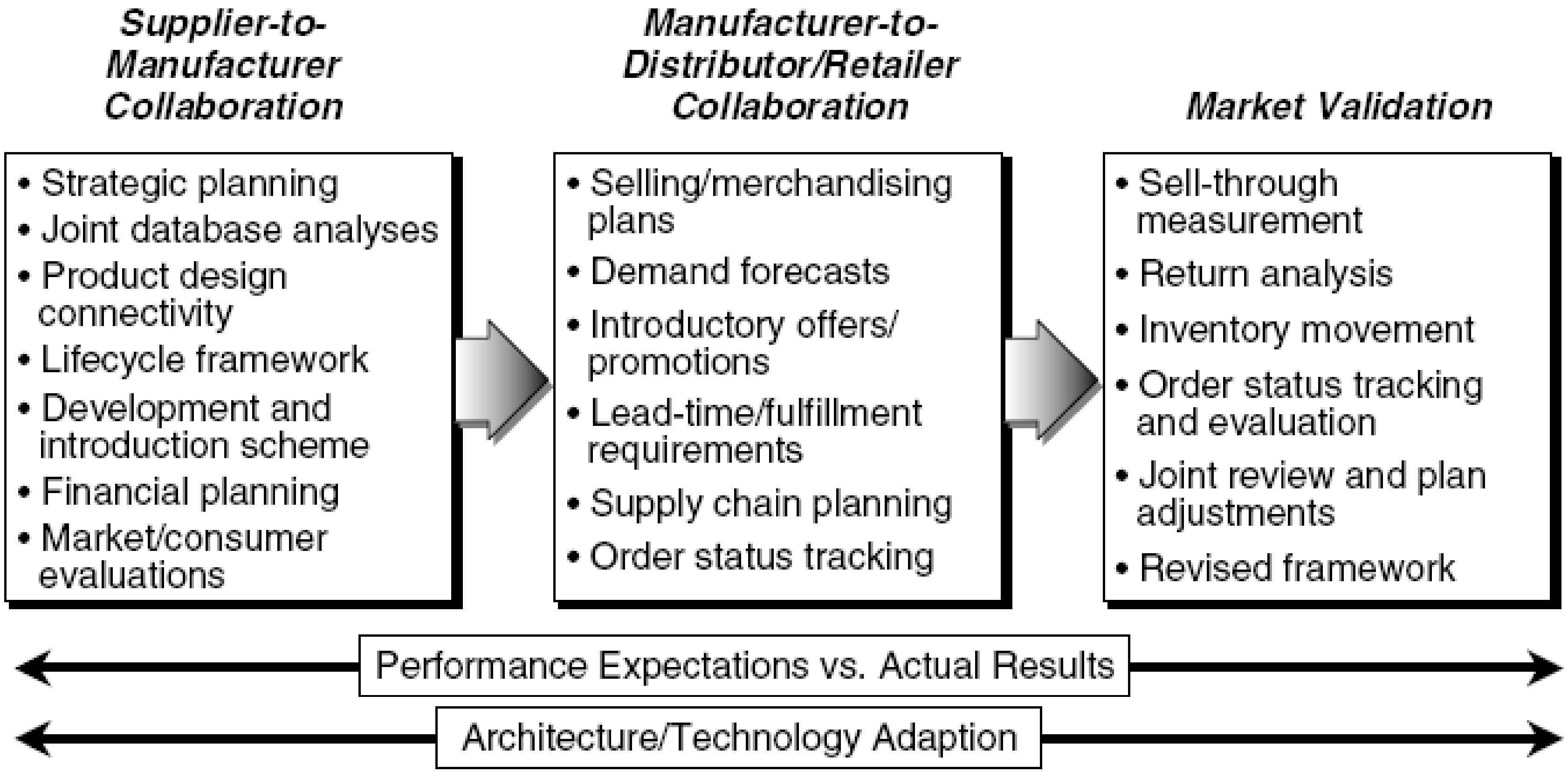
COLLABORATION MUST BECOME AN ACCEPTED PRINCIPLE

- To begin a convincing argument, we should first accept that informal alliances have been on the business scene for some time as firms build close relationships with business partners they know can assist with supply chain activities, even product design.
- What is new, and becomes part of a more mature supply chain system, is the ability to link communications and cooperation across an end-to-end network and deliver innovative goods and services to targeted customers and consumers in record time and in a user-friendly manner.
- Through the application of information technology and cyber-based communication, firms around the world find they can collaborate on a full-time, real-time basis and transfer data, drawings, specifications, ideas, prototype information, and new designs among trusted allies in a network effort to gain the high ground in a market.
- Those in manufacturing also find that building the products becomes easier as synchronized flows and full network acceptance of specifications make the new products more compatible with manufacturing capabilities.

- **A CONTEMPORARY FRAMEWORK GUIDES EXECUTION** To appreciate the linkage between collaboration, technology, and product design, we should start with a few simple observations.
- Collaborating and applying technology for product design and development with trusted supply chain partners is a powerful modern management tool aimed at improving costs and the time to market for successful new product introductions.
- The technique is advancing rapidly, especially in industries where external partners, such as contract manufacturers and subassembly suppliers, are an important factor in completing the work.
- Where multiple design engineering cooperation and specific outsourcing of key components are involved, the technique becomes a requirement for success. Online visibility and real-time information sharing become the elements used, leading to tracking progress across the full life cycle of the new product or service.
- Included in a typical effort will be a complete product design history — from initial concept to product use, disposal, or recycling — including quality assurance and use and repair information

- Contemporary applications are constructed around a closed-loop process that begins with customer requirements and ends with successful introductions and renewals when appropriate.
- Most of the current systems came from an earlier effort at using computer-aided design (CAD) and computer-aided manufacturing (CAM) and product data management (PDM) systems, which were used to support business partners with online systems for creating and managing products and processes across an extended enterprise while maintaining living documentation of what was occurring as the product went to market.

Product Life Cycle Management



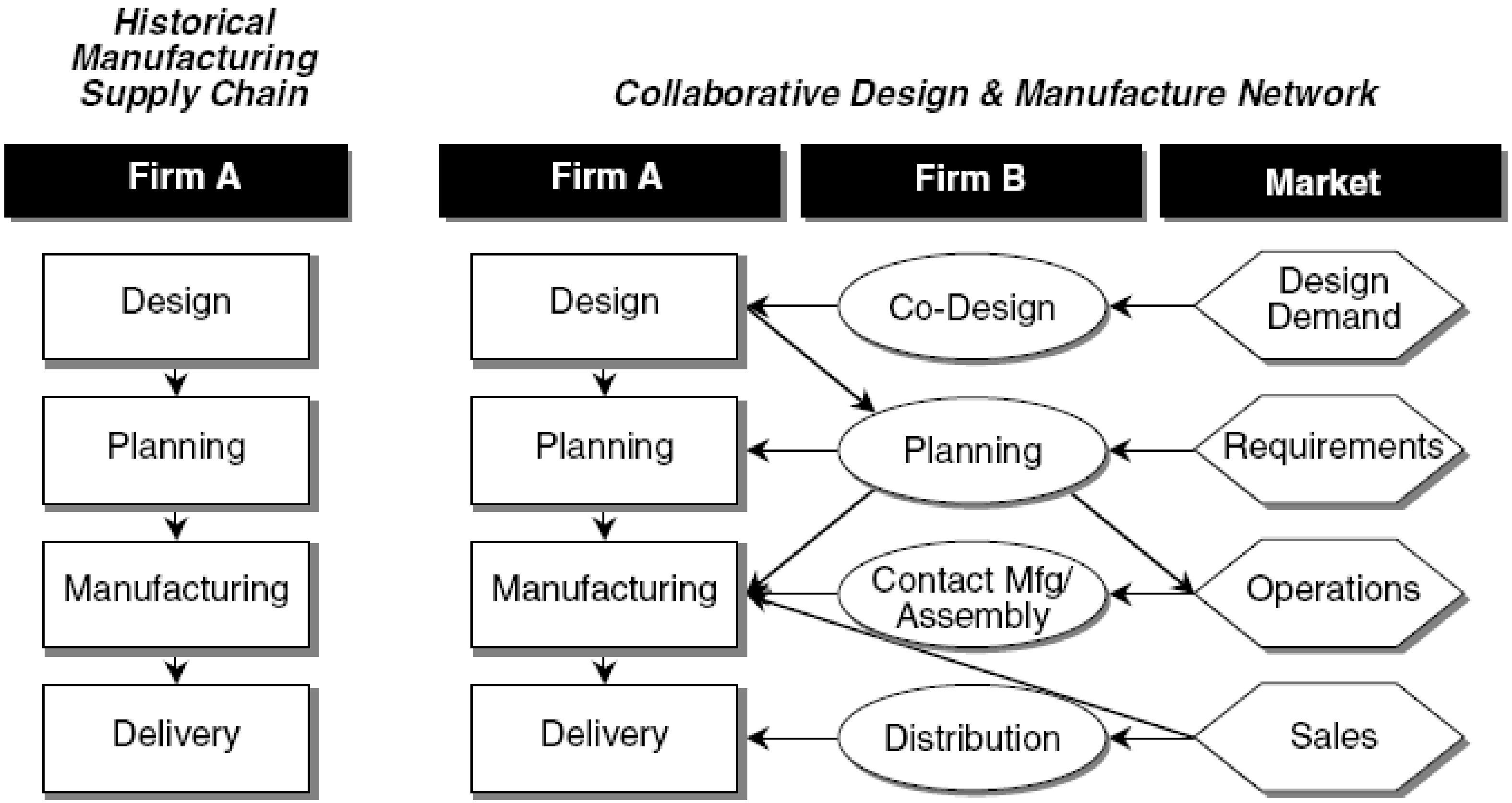
- key suppliers are invited to participate in strategic planning around new developments and product introductions, as are internal representatives from operations.
- Together, the partners begin analyzing their capabilities and scouring their collective databases, sharing information pertinent to what the market needs and will accept and what they can provide better than any competitor.
- Generally, the partners find that bringing insights to this analysis from different perspectives helps select the right products and enhances the finished designs while better utilizing manufacturing capabilities.

•Next, teams are established to begin co-designing new products or enhanced make-overs through a communications extranet established for that purpose. In the automobile example, suppliers and subassembly manufacturers have linked their design systems to that of the original equipment manufacturer (OEM) and are allowed to recommend new designs that match the OEM’s manufacturing capability.

•In aerospace, it is now not unusual for a supplier to assume responsibility for the design of an entire major component of the finished aircraft. As the co-designing proceeds, a means to track the lifecycle of the products is accepted, usually through a merger of existing techniques.

•The teams then focus on the actual development, taking advantage of core competencies so the most effective partner assumes responsibility for the appropriate design steps.

Network Product Design



- In Level 2, as the internal barriers to cooperation tumble down, projects are coordinated across domestic and global locations, using simple communications and the intranet set up for such purposes.
- Concurrent engineering methods are in place, as are metrics to measure improved conditions. The emphasis moves toward introducing shared or reusable components from similar sources to reduce costs.
- Typically, we see at least a 30% reduction of suppliers. In one example of processing in this level, a major car manufacturer insisted that product life cycle management be viewed as an enterprise system that had to be integrated with other corporate initiatives to optimize benefits from the development effort.

Design and Development of Products

I Process Optimization *Divisional*	II Internal Excellence *Intra-Enterprise*	III Network Formulation *Inter-Enterprise*	IV Value Delivery System *External*	V Value Delivery Network *Total Business System*
• Product development groups co-located, loosely organized and independent • Develop products without regard to commercialization and sourcing • Share common components internally for easily identified commodities • Minimal CAD/CAM information shared with suppliers • Local management of change control	• Projects coordinated across domestic/global locations using simple communication tools • Apply concurrent engineering methods (e.g., DF*) and begin to use key metrics, but not consistently • Emphasize use of shared, reusable components/sources • Reduce to 30% engineered component supplier	• Product development across several global locations using leading-edge communication tools (Web-based applications) • Involve key partners and suppliers early to co-design and rationalize capabilities, knowledge and costs • Develop shared data repositories to reduce version control errors • Metrics used consistently and rolled up for analysis	• Product development using leading-edge communication tools is structured to occur and be coordinated anywhere • Reduce time to commercialization and scale • Suppliers integrated into technology/product roadmaps • Collaborative design process involves 2nd- and 3rd-tier suppliers • Capture, share and review all design rationale with each business partner	• Dispersed teams function effectively to support design/manufacture anywhere in the network • Apply cross-enterprise scheduling tools for distributed projects • Product information from all partners captured and managed across lifecycle with consistent processes • Comprehend value-added services into product design/development across lifecycle

THIRD LEVEL

- The third level begins the external partnering so vital to significant improvement in design and manufacturing.
- Now product development is done across several locations with the help of carefully selected suppliers using an extranet, leading-edge tools, and Web-based applications.
- Key external partners are involved early in the process to co-design and rationalize joint capabilities as they apply to development.
- The linked partners in the network develop shared data repositories to significantly reduce the costs of changes and moving through various versions of design.
- Jointly developed metrics are in play and used consistently throughout the roll-out and follow-up analysis.

•In Level 4, where the value delivery system appears, product development advances to the point where the partners are using highly sophisticated communication tools, often based around business process management (BPM) tools.

•The time from concept to commercial acceptance is reduced dramatically, often by at least 30%, but with some firms achieving 50% or more.

•Key suppliers are integrated into the technology and product development and introduction road maps are extended to second- and third-tier suppliers collaborating with the development effort.

- Level 5 is rarefied and only a few organizations and their business partners have achieved this degree of full network connectivity and are working with a full business-system approach.
- In this most advanced area, dispersed teams, staffed by partners across the network, function effectively to support what has become a collaborative design and manufacturing effort.
- Cross-enterprise tools are used for scheduling and delivery. Product information across the life cycle of the new introductions is captured from each participant and managed with consistent processes.
- The value-added services that accompany the products are documented and made a part of future design and development efforts

- When the design process is interactive and jointly managed across a network, an important feature appears, and that is the ability to manage the design information across the supply chain from supplier to customer delivery and final disposition.
- This ability facilitates handling product changes or modifications , dealing with engineering change orders, coping with product obsolescence or the need for modifying design, and accessing a partner's enterprise wide resource planning (ERP) system to maintain a proper information flow regarding the product's acceptance or failure.
- Logistics data, delivery results, maintenance and repair requirements, and customer use can be analyzed to determine how to avoid and solve problems.
- In some contemporary systems, there is an ability to track details down to the crew name and date of manufacture.

USING REVENUE SHARING TO ACHIEVE CHANNEL COORDINATION

The idea of channel coordination is that a manufacturer, through its pricing strategy, will ensure that an independent vendor will order the same amount as if the manufacturer controlled the vendor. In such cases the total expected profit for the channel is maximized. Channel coordination is desirable to a manufacturer since if total channel profits are maximized while the vendor’s expected profit remains constant, the manufacturer’s expected profit will be maximized.

- c_1 = the vendor's cost per unit if the vendor obtains the item from the manufacturer through outright purchase.
- p_1 = the retail price per unit and therefore the vendor's revenue per unit if the vendor obtains the item from the manufacturer though outright purchase.
- s = the vendor's salvage value per unit if the vendor obtains the item from the manufacturer through outright purchase.
- g = the vendor's goodwill cost per unit if the vendor is out of stock of the item.

- m = the manufacturer's production cost per unit.
- c_2 = the vendor's cost per unit if the vendor obtains the item from the manufacturer on consignment.
- p_2 = the vendor's revenue per unit if the vendor obtains the item from the manufacturer on consignment. (Note that $p_1 - p_2$ equals the revenue paid to the manufacturer if an item purchased on consignment is sold by the vendor.)

- Q_1 = the number of units the vendor obtains from the manufacturer through outright purchase.
- Q_2 = the number of units the vendor obtains from the manufacturer on consignment.
- Q = the number of units ordered if the supply channel is coordinated.
- $EV(Q_1, Q_2)$ = the vendor's expected profit if it purchases Q_1 units and obtains Q_2 units on consignment.
- $EM(Q_1, Q_2)$ = the manufacturer's expected profit if the vendor purchases Q_1 units and obtains Q_2 units on consignment.

- $EP(Q)$ = the total expected channel profit if the channel is coordinated and the order quantity is Q.
- Q_1^* = the optimal number of units the vendor should obtain from the manufacturer through outright purchase if the vendor wishes to maximize its expected profit.
- Q_2^* = the optimal number of units the vendor should obtain from the manufacturer on consignment if the vendor wishes to maximize its expected profit.
- Q^* = the optimal number of units ordered for a coordinated supply channel.
- $f(x)$ = the probability density function of demand.

We will assume that due to competitive pressure, the values of c_1, p_1, s, g, and m are fixed[1], however the manufacturer has control over setting the values of c_2 and p_2. Given the cost structure set by the manufacturer, the vendor will then determine the order quantity that maximizes its expected profit.

Following this notation, we see that if the vendor purchases the item outright from the manufacturer, the vendor earns a gross profit of $p_1 - c_1$ for each unit sold and the manufacturer earns a gross profit of $c_1 - m$ for each unit ordered by the vendor.

vendor earns a gross profit of $p_1 - c_1$

manufacturer earns a gross profit of $c_1 - m$

If however, the vendor orders the item from the manufacturer on a consignment basis, the vendor would pay the manufacturer c_2 per unit plus an amount equal to $p_1 - p_2$ for each unit sold. As a result, for each unit purchased on consignment and sold by the vendor, the vendor earns a gross profit of $p_2 - c_2$ and the manufacturer earns a gross profit of $p_1 - p_2 + c_2 - m$.

vendor earns a gross profit of $p_2 - c_2$

manufacturer earns a gross profit of $p_1 - p_2 + c_2 - m$.

We further assume that if the vendor purchases the item outright from the manufacturer the salvage value, s, from each unsold unit accrues to the vendor, whereas if the item is obtained from the manufacturer on a consignment basis the salvage value accrues to the manufacturer. In all cases the goodwill cost per unit due to shortage, g, is assumed to accrue to the vendor.

COST RELATIONSHIP

- $p_1 > p_2$ (The vendor's revenue per unit is greater if it purchases the item than if it obtains the item on consignment.)
- $c_1 > c_2$ (The vendor's cost per unit is greater if it purchases the item than if obtains the item on consignment.)
- $c_1 > s$ (The vendor's cost per unit for purchasing the item is greater than its salvage value)
- $p_1 > c_1$ (For items purchased, the vendor's revenue per unit is greater than the cost per unit.)
- $p_1 - p_2 > c_1 - c_2$ (For it to be worthwhile for the manufacturer to offer the item to the vendor on a consignment basis, the manufacturer's gross profit per unit from consignment should be greater than the gross profit from outright sale to the vendor. This also states that the vendor's gross profit per unit from outright purchase is greater than if it obtains the item on consignment.)

$$EV(Q_1, Q_2) =$$

$$\int_{0}^{Q_1} [p_1 x + s(Q_1 - x)] f(x) dx + \int_{Q_1}^{Q_1+Q_2} [(p_1 - p_2)Q_1 + p_2 x] f(x) dx$$

$$+ \int_{Q_1+Q_2}^{\infty} [p_1 Q_1 + p_2 Q_2 - g(x - Q_1 - Q_2)] f(x) dx$$

$$- c_1 Q_1 - c_2 Q_2 \tag{6.1}$$

$$EM(Q_1, Q_2) = \int_0^{Q_1} sQ_2 f(x)dx$$

$$+ \int_{Q_1}^{Q_1+Q_2} [(p_1 - p_2)(x - Q_1) + s(Q_1 + Q_2 - x)] f(x)dx$$

$$+ \int_{Q_1+Q_2}^{\infty} (p_1 - p_2)Q_2 f(x)dx + (c_1 - m)Q_1 + (c_2 - m)Q_2. \quad (6.2)$$

The problem faced by the vendor is therefore:

$$\text{Maximize} \quad EV(Q_1, Q_2) \qquad (P1)$$

$$\begin{aligned} s.t. \quad & -Q_1 \le 0 \\ & -Q_2 \le 0. \end{aligned}$$

The partial derivatives of $EV(Q_1, Q_2)$ are as follows:

$$\frac{\partial EV(Q_1, Q_2)}{\partial Q_1} = F(Q_1)(s - p_1 + p_2) - F(Q_1 + Q_2)(p_2 + g) - c_1 + p_1 + g \quad (6.3)$$

and

$$\frac{\partial EV(Q_1, Q_2)}{\partial Q_2} = [1 - F(Q_1 + Q_2)](p_2 + g) - c_2 \quad (6.4)$$

(1) $Y_1 Q_1^* = 0$

(2) $Y_2 Q_2^* = 0$

(3) $F(Q_1^*)(s - p_1 + p_2) - F(Q_1^* + Q_2^*)(p_2 + g) - c_1 + p_1 + g = -Y_1$

(4) $[1 - F(Q_1^* + Q_2^*)](p_2 + g) - c_2 = -Y_2$

(5) $Y_1 \geq 0, Y_2 \geq 0, Q_1^* \geq 0, Q_2^* \geq 0$

where Y_1 and Y_2 are the Lagrange multipliers (dual variables) for this problem.

We also see that:

$$\frac{\partial^2 EV(Q_1,Q_2)}{\partial Q_1^2} = f(Q_1)(s-p_1+p_2) - f(Q_1+Q_2)(p_2+g) \quad (6.5)$$

$$\frac{\partial^2 EV(Q_1,Q_2)}{\partial Q_2^2} = -f(Q_1+Q_2)(p_2+g) \quad (6.6)$$

and

$$\frac{\partial^2 EV(Q_1,Q_2)}{\partial Q_1 \partial Q_2} = -f(Q_1+Q_2)(p_2+g). \quad (6.7)$$

By looking at the second-order partial derivatives for $EV(Q_1, Q_2)$ we note that if $p_1 - p_2 - s \geq 0$, then $EV(Q_1, Q_2)$ is concave.

Theorem 6.1 states that it would never pay for the vendor to obtain the item from the manufacturer only on a consignment basis.

Theorem 6.1 *It is impossible for* $Q_1^* = 0$ *and* $Q_2^* > 0$

Proof: If $Q_2^* > 0$ then from KKT condition (2) $Y_2 = 0$. Hence, from KKT condition (4) we have:

$$F(Q_1^* + Q_2^*) = (p_2 + g - c_2)/(p_2 + g). \qquad (6.8)$$

Substituting equation (6.8) into KKT condition (3) gives:

$$F(Q_1^*)(s - p_1 + p_2) + (p_1 - p_2 - c_1 + c_2) = -Y_2. \qquad (6.9)$$

But if $Q_1^* = 0$, then $F(Q_1^*) = 0$ and it would be impossible for equation (6.9) to be satisfied.

Theorem 6.2 *If* $\frac{p_2+g}{c_2} > \frac{p_1+g-s}{c_1-s}$, *then it is impossible for* $Q_1^* > 0$ *and* $Q_2^* = 0$.

Proof: Suppose $Q_1^* > 0$. Then from KKT condition (1) we have $Y_1 = 0$. If we also assume that $Q_2^* = 0$, from KKT condition (4) we have:

$$F(Q_1^*) = \frac{p_2+g-c_2+Y_2}{p_2+g} \qquad (6.10)$$

while from KKT condition (3) we have:

$$F(Q_1^*) = \frac{p_1+g-c_1}{p_1+g-s}. \qquad (6.11)$$

But, if $\frac{p_2+g}{c_2} > \frac{p_1+g-s}{c_1-s}$, then $\frac{p_2+g-c_2+Y_2}{p_2+g} \geq \frac{p_2+g-c_2}{p_2+g} > \frac{p_1+g-c_1}{p_1+g-s}$.

In essence, what Theorem 6.2 states is that if the ratio of revenue to cost for goods obtained on consignment is high enough, it will never be optimal for the vendor to only purchase the good. Such a condition will occur if the salvage value is low and the goodwill cost is high.

In such cases the optimal amount for the vendor to purchase and to obtain on consignment can be determined by recognizing that $Y_1 = Y_2 = 0$ and solving for KKT conditions (3) and (4). This gives the following relationships for Q_1^* and Q_2^*.

$$F(Q_1^* + Q_2^*) = \frac{p_2 + g - c_2}{p_2 + g} \quad (6.12)$$

and

$$F(Q_1^*) = \frac{p_1 - p_2 + c_2 - c_1}{p_1 - p_2 - s} \quad (6.13)$$

Theorem 6.3 *If* $s > c_1 - c_2$, *then* $F(Q_1^*) = \frac{p_1 + g - c_1}{p_1 + g - s}$ *and* $Q_2^* = 0$.

Proof: We show in this case that it is impossible for both $Q_1^* > 0$ and $Q_2^* > 0$. In particular, if $Q_1^* > 0$ and $Q_2^* > 0$, then KKT conditions (1) and (2) imply that $Y_1 = Y_2 = 0$. Hence, equations (6.12) and (6.13) must be satisfied. But if $s > c_1 - c_2$ then from equation (6.13) we would have $F(Q_1^*) > 1$, which would be impossible. Also, we know from Theorem 6.1 that it is impossible for $Q_1^* = 0$ and $Q_2^* > 0$. Hence, $Q_1^* > 0$ and $Q_2^* = 0$. The result follows from KKT condition (3).

Theorem 6.3 states that if the salvage value per unit is greater than $c_1 - c_2$, then the vendor would obtain all items through outright purchase.

Theorem 6.4 *If the manufacturer wishes to achieve channel coordination then it will be necessary to set* $c_2 = \frac{(p_2+g)(m-s)}{p_1+g-s}$.

Proof: Clearly, if the manufacturer wishes to achieve channel coordination, it must set the price for the goods obtained on consignment at an attractive enough level so that $Q_2^* > 0$. We know from Theorem 6.1 that it is impossible for $Q_1^* = 0$ and $Q_2^* > 0$ and from Theorem 6.3 that if $s > c_1 - c_2$ then $Q_2^* = 0$. Hence, c_2 must be set such that $c_1 - c_2 \geq s$ and we will focus on the case where $Q_1^* > 0$ and $Q_2^* > 0$.

If the channel is coordinated, from the results of the standard newsboy model it must be true that Q_1^* and Q_2^* satisfy the following relationship:

$$F(Q_1^* + Q_2^*) = \frac{p_1+g-m}{p_1+g-s} \tag{6.14}$$

Also, we know from KKT condition (4) that:

$$F(Q_1^* + Q_2^*) = \frac{p_2+g-c_2}{p_2+g} \tag{6.15}$$

Equating the two expressions for $F(Q_1^* + Q_2^*)$ results in the relationship for c_2.

Corollary 6.5 *It is necessary to set* $c_2 < (m - s)$ *in order to achieve channel coordination.*

Proof: Equating (6.14) and (6.15) gives:

$$(m - s)(p_2 + g) = c_2(p_1 + g - s) \tag{6.16}$$

The result follows since $p_1 - p_2 > c_1 - c_2 \geq s$ and therefore $p_1 - s > p_2$.

The implication of Theorem 6.4 and Corollary 6.5 is that for the manufacturer to achieve channel coordination, it would have to offer consigned goods to the vendor at a cost that is less than the manufacturer's production cost minus the good's salvage value.

Theorem 6.7 *If demand follows a uniform distribution and the manufacturer wishes to set consignment pricing to achieve channel coordination, the manufacturer will need to set* c_2 *to be less than or equal to* $(m - s)/2$ *in order for its expected profits to not decline.*

EXAMPLE

$p_1 = \$100, c_1 = \$40, s = \$10, g = \$100, m = \$20,$ and $f(x) = U(0, 95).$

If the vendor does not have the option of obtaining items through consignment, we know from the newsboy problem solution that the vendor's optimal purchase quantity would be $Q_1^* = 80$. In this case the vendor would earn an expected profit of:

$$\begin{aligned} EV(80) &= \int_0^{80} [100x + 10(80 - x)] \frac{1}{95} dx \\ &\quad + \int_{80}^{95} [100 * 80 - 100(x - 80)] \frac{1}{95} dx - 40 \cdot 80 \\ &= \$1,650 \end{aligned}$$

and from equation (6.24) we have that the manufacturer would earn a profit of 80 • (\$40 – \$20) = \$1,600. Total channel expected profit in this case would therefore be \$3,250.

Under channel coordination, the optimal order quantity would satisfy the relationship: $F(Q^*) = \frac{p_1 + g - m}{p_1 + g - s}$, which for this example, results in a value of $Q^* = 90$. The total channel expected profit in this case would be:

$$\begin{aligned} EP(90) &= \int_0^{90} [100x + 10(90 - x)] \frac{1}{95} dx \\ &\quad + \int_{90}^{95} [100 \cdot 90 - 100(x - 90)] \frac{1}{95} dx - 20 \cdot 90 \\ &= \$3,350. \end{aligned}$$

Now, let us assume that the manufacturer offers the good on consignment to the vendor at a cost of \$8, e.g. $c_2 = 8$. We know from Theorem 6.4 that p_2 should be set to satisfy the relationship:

$p_2 = \dfrac{c_2(p_1 + g - s)}{m - s} - g$. Hence, p_2 should be set equal to 52.

In this case, we can use equations (6.12) and (6.13) to determine the values of Q_1^* and Q_2^*. Solving the relationships:

$$F(Q_1^* + Q_2^*) = 0.94737 \text{ and } F(Q_1^*) = 0.42105$$

gives $Q_1^* = 40$ and $Q_2^* = 50$.

For these values the vendor's expected profit would be:

$$EV(40,50) =$$
$$= \left[\frac{(100-52-40+8)^2}{100-52-10} + \frac{(52+100-8)^2}{52+100} - 100\right]\frac{(95-0)}{2}$$
$$= \$2,050$$

and the manufacturer's expected profit would be:

$$EM(40,50) =$$
$$= \left[\frac{(100+100-20)(40-20)}{(100+100-10)} - \frac{(40-20)^2}{2(100-52-10)}\right](95-0)$$
$$= \$1,300.$$