

## Chapter 2

# Performance Evaluation and Value Chains

A supply chain system can only achieve top performance if it finds a way of fulfilling its mission while ensuring that managerial actions make a positive contribution at every step of the way. Success depends on the mission being broken down into a set of objectives and performance indicators that will help to determine priorities and promote good decision-making. A strategy is of no use if it does not come together with performance indicators concretizing its aims. On the other hand, what a responsibility center measures is often the only thing deemed important. Consequently, a misalignment between missions and performance indicators does not only lead to a waste of resources, but it may endanger the company's overall success.

Chapter 1 stressed that the fundamental mission of a supply chain system is continuous value creation for the company and its partners. The performance indicators that a company adopts must therefore contribute to value creation, the latter being defined as the discounted sum of all future revenues, operating expenses, and capital expenditures. The fulfillment of this ultimate aim can be verified using financial performance indicators such as EVA and ROCE. These systemic indicators are crucial for top management but they are not appropriate for supply chain operations managers. Ultimately, performance depends on operations, not on strategies. Hence, the need to identify value drivers leading to suitable performance indicators for the responsibility centers of the supply chain system. These indicators do not have to be financial in nature and can be expressed, for instance, in terms of time (cycle times, setup times, delivery times, etc.), process productivity or reliability (products/hour, defect rate, failure rate, fill rate, etc.), and/or resource use (capacity utilization rate...).

This may lead to the definition of large numbers of indicators. The proliferation of measures can become problematic, because either it requires too much effort or it masks fundamental underlying behaviors. Designing a performance evaluation system that is balanced and congruent with a company's mission can be a challenge. After discussing several facets of this problem, the chapter looks at ways of evaluating a supply chain system's economic performance. More specifically, it studies the modeling of the revenues and costs necessary to design value-creating

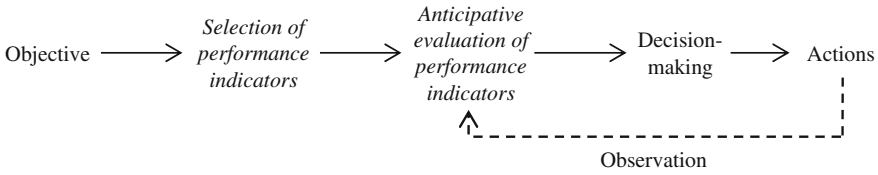
networks. Since these networks must be designed to provide superior performance during several years, future results are necessarily uncertain, and the measurement of value-at-risk over the planning horizon considered is also discussed.

## 2.1 Performance Evaluation in SC Management

A performance indicator is a verifiable measurement associated with a performance object. A measurement is *verifiable* if it is based on an estimation process specifying the data and calculation methods required to obtain the indicator. The *performance object* refers to what is being evaluated. It depends on where we are looking (forward or backward), on what we are trying to do (control, improve or communicate), and on the level of the responsibility centers that it affects. An indicator must elucidate what allows the responsibility center to create value for the company and its customers. As such, it should ideally be tied to value drivers, that is, to factors affecting the value added by the center.

When the purpose is to control operations or communicate outcomes, it is necessary to look backwards, with a focus on the outcomes achieved with the actions taken over a given time period. Once relevant observations have been made, the calculation method specified is used to evaluate the indicator. To control operations, this evaluation is compared with pre-set targets. These can be absolute standards like zero defects or the complete elimination of downtime; internal aims like budgets, standard times, and improvement targets; or industrial benchmarks like environmental standards or matching top-performing companies in the industry. Benchmarks of this kind are published by specialist organizations such as the Supply Chain Council (now part of APICS—[www.apics.org](http://www.apics.org)), which has, for instance, collaborated with APQC ([www.apqc.org](http://www.apqc.org)) to develop a SCORmark<sup>SM</sup> benchmark for its members. The performance indicators provided in the SCOR (*Supply Chain Operations Reference*) model allow a comparison with the best practice in the field of supply chain management. Furthermore, the publication of periodic financial statements is a perfect example of how one can proceed to communicate results.

If, on the other hand, the purpose is to improve supply chain system performance, it is necessary to look forward. Figure 2.1 shows how to proceed to make improvement decisions. The first step is to set an objective, then comes the choice of performance indicators and the evaluation of these indicators, decisions are made, and lastly, an action is taken. Decisions can entail short-term execution, operational or tactical planning, and even supply chain network reengineering. The ensuing actions should normally contribute to achieve the objective. Ex post, this is verifiable through the chosen performance indicators. Ex ante, these indicators become an essential element of the decision-making process, which relies on a formal or informal optimization model grounded in the perceived relationship between the decisions that must be made and expected performance. Where a formal normative model is used, performance indicators are associated with certain



**Fig. 2.1** Performance indicators' role in decision-making

model parameters. If the objective is to minimize relevant costs, the model's economic function could, for instance, associate operating costs with activity levels, and acquisition costs with added resources. Its capacity constraints would require parameters such as the resources consumed by unit of activity, the inventory turnover ratio, and so forth. If future decisions relate to short-term operations management, it is reasonable to assume that latest ex post indicator estimates suffice to forecast future behavior. On the other hand, when making long-term decisions, this assumption is generally unrealistic and consideration must be given to evolutionary trends associated with plausible futures. It is then no longer sufficient to rely on static performance indicators calculated using historic observations. Instead, performance functions depending on a number of contextual variables must be used. The estimation of these functions involves regression analysis as much as management accounting techniques.

In addition, the method used to estimate performance indicators/functions from operational data (quantities, loads and delays associated with purchases, deliveries, production, inventory, and sales, as well as with the resources employed) largely depend on what we want to do, and more broadly on the underlying performance model. This shows the importance of congruence between decision-making and performance models. Take the example of a product unit cost. Suppose a responsibility center uses space, equipment, and staff to transform raw materials into finished products. To set an adequate sales price for these products, it is important that the unit production cost calculated covers all the resources used. Using activity-based costing (ABC), the cost of the resources used during a particular period can be allocated to products, enabling the calculation of unit production costs that are good enough to set sales prices. Assume now that different equipments with different costs and throughputs (which affects staffing needs) can be used to make the products, and that the quantity of each product to make on each equipment must be planned to minimize production costs over the next week in light of the capacity available for each equipment and the volume of customer orders received. To be able to elaborate an optimal production plan, a distinct production cost must be calculated for each product on each piece of equipment. The ABC costs calculated cannot be used to do this because they are associated with historic production plans (looking backwards instead of forward) and they do not distinguish between equipment. This is why accounting system-based costs often cannot be used to optimize supply chain network planning and design decisions.

The objective pursued and the associated performance objects depend on the level of the responsibility center considered. A responsibility center is a generic group of resources pursuing a particular objective, and it must define performance indicators to plan and control its activities. Since a supply chain generally cuts across several companies that may include several strategic business units (SBUs) organized into departments performing production or service activities, a hierarchy of performance objects must be specified. At the top level, a responsibility center could encompass the whole of a supply chain, or else correspond to an actual company. Conversely, at the local level, it can be limited to a specific process. At the top level, performance indicators that focus on value creation (EVA, ROCE, etc.) and performance failure risks (value-at-risk, downside risk, etc.) are favored. Locally, the focus might be on the total cost of a subsystem or process, or on measures like response times, defect rates or productivity indexes. As aforementioned, indicators are useful if they are linked to value drivers. For instance, a relevant indicator for a distribution center may be the “average number of pallets loaded per truck” since this creates an incentive to reduce the resources required for shipments. An indicator like “percentage of on-time deliveries” is also useful because it relates directly to an order winner valued by customers. By relying on the definition of residual cash flows (RCF) and on the discussions featured in Chap. 1, four main categories of value drivers can be distinguished:

- Drivers that help to increase revenues by affecting order winners valued by customers;
- Drivers that help to reduce operating costs and current assets (inventory and receivables) by improving processes;
- Drivers that help to reduce fixed assets by improving network structures and interfaces with the environment (strategic alliances);
- Drivers that help to reduce risk.

The most widely used tool for tracking performance is a scorecard. To help fulfill a company’s mission and to implement its business strategy, Kaplan and Norton (1992, 1996) have suggested using balanced scorecards such as the one illustrated in Fig. 2.2. The basic idea is to allow senior managers to monitor a company from four complementary perspectives by observing a limited number of performance indicators revolving around mission and strategy. The indicators chosen address four basic issues:

- How do customers see us? (Customer perspective)
- What must we excel at? (Internal business perspective)
- Can we continue to improve and create value? (Innovation and learning perspective)
- How do we look to shareholders? (Financial perspective).

Since this textbook focuses on reengineering supply chain networks, it will not emphasize performance monitoring but instead the prospective evaluation of alternative networks’ performance over a multi-year planning horizon. At the strategic level, since value creation is the main objective, the SCN designs

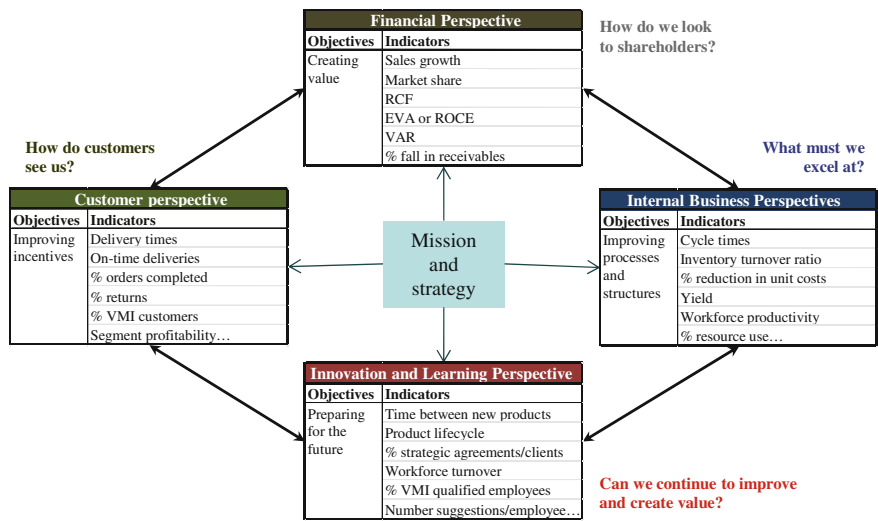


Fig. 2.2 The balanced scorecard. Adapted from Kaplan and Norton (1992, 1996)

considered are evaluated essentially from an economic point of view, that is, using expected value and value-at-risk measures. Two approaches have been widely used for this kind of strategic decision-making. Management accounting generally compares a number of alternatives developed by managers to the status quo (the default solution if nothing is done) by preparing differential investment budgets. These investment budgets identify the operating revenues and expenditures, as well as the capital expenditures, modifications induced by an alternative over the status quo for a given planning horizon. However, there is no guarantee that the alternatives considered would perform particularly well. Hence the second approach, which involves formulating a mathematical programming model with an objective function enclosing all relevant expected monetary flows, and possibly a risk evaluation. Where the mathematical model captures the essence of the problem, this approach leads to solutions that are close to the optimum.

Independently of the approach, to obtain valid results, the explicit or the implicit comparison of designs must be made over the same planning horizon. In addition, consideration should be given to all relevant monetary flows across the supply chain. The fact that several partners (customers, subcontractors, 3PLs, suppliers, etc.) might be involved can cause serious difficulties. When the supply chain system is in a stationary state, it may be sufficient to compare monetary flows over one year. This is not trivial, however, because operational revenues and costs are incurred on a daily basis, but capital expenditures provide resources whose productive life lasts several years. To perform such evaluations, it is therefore necessary to aggregate daily material and monetary flows, and to calculate an investments' annual "lease." If the system is not in a stationary state—due, for instance, to companies' desire to conquer new markets or increase market share—a

multi-year planning horizon must be considered. This raises questions as to the value of money over time and of fixed assets' value at the end of the planning horizon. These concerns are examined in detail below.

## **2.2 Economic Performance Measurement**

Corporate supply chain costs are often difficult to determine due to the inability of financial and management accounting systems to isolate them. Accounts defined for financial monitoring purposes are generally associated with resource categories (labor, equipment, buildings, etc.) and they are elaborated to be able to report past financial results. The cost functions required for prospective supply chain system evaluations may be derived from corporate accounting information, but their estimation usually requires a reorganization of available accounting data. In this section, before examining the revenues and costs relevant to strategic supply chain decision-making, we review the fundamental nature of costs, as well as issues related with investment projects evaluation.

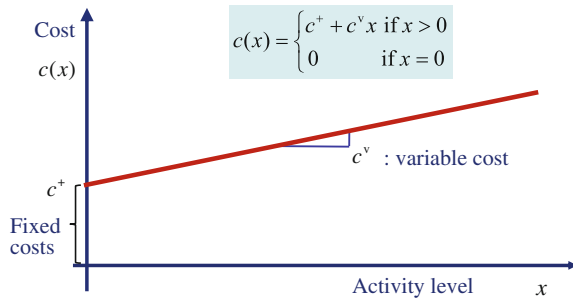
### ***2.2.1 Cost Accounting and Cost Functions***

Companies estimate different types of costs. Not all are relevant to decision-making, however. It is important to understand the fundamental nature of costs to determine which to consider in a particular decision-making context. Estimating costs is the purpose of management accounting but, as aforementioned, the approach required to estimate a cost depends on what we want to do, that is, on the decision-making process requiring it. When looking forwards, a cost is not a fact but a prospective anticipation. Costs can be fixed or variable or a mixture of the two, and in some cases, they are affected by economies of scale or scope. A distinction must also be made between unit and marginal costs, historic and opportunity costs, relevant and sunk costs, and between operating and capital expenditures. The next paragraphs explain all of these concepts.

#### **2.2.1.1 Fixed and Variable Costs**

*Fixed* costs do not depend on the volume of activity during a given time period. Activity volumes are typically expressed as quantities produced, stocked, shipped, and so on. Wages paid to a company supervisory or support staff members are fixed costs since they do not vary depending on the volume of activity. Other expenses such as building leases, heating, or electricity are fixed but considered “indirect” because it is difficult to associate them with a specific product. Conversely, costs

**Fig. 2.3** Representation of a mixed (fixed plus variable) cost function



that evolve depending on activity levels are called *variable*. The cost of the raw materials used to make a product is variable because the quantities needed depend on the number of products being manufactured. Similarly, the costs of the workers employed directly to transform materials into products are variable.

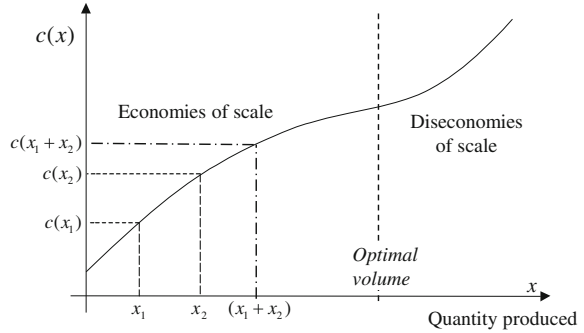
Most activities have costs that are partially fixed and variable. The fixed portion involves costs incurred to set up or use a process, and the variable part depends on an activity variable such as the run time or the quantity produced. The cost for using a workstation combining equipment and human operators to manufacture specific products is generally mixed since it contains a fixed setup cost as well as a variable production cost. Figure 2.3 illustrates the cost function thus defined. The cost  $c(x)$  incurred to make  $x$  products is the sum of fixed cost  $c^+$  and a variable cost  $c^v$  for each unit produced.

### 2.2.1.2 Economies of Scale and Scope

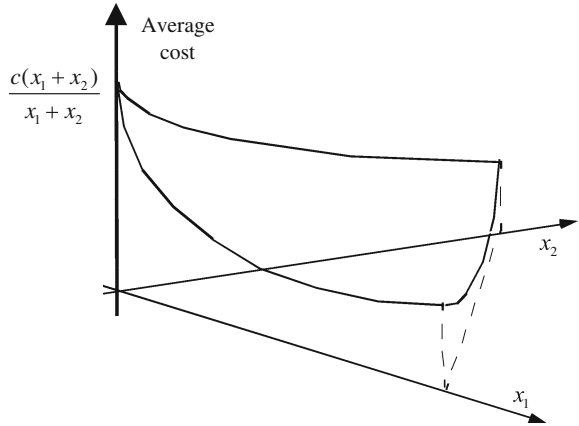
The cost function  $c(x)$  represented in Fig. 2.3 is linear, because it assumes that the variable cost is directly proportional to the volume of activity. In fact, given the possibility of achieving economies of scale or scope, this linearity assumption does not always apply. Economies of scale happen when marginal costs fall as activity levels increase. Thus, a product costs less to make as production quantities rise. Economies of scale stem from a number of factors such as learning effects, the use of higher performance technologies, a better utilization of available capacities, quantity discounts offered by suppliers and transportation companies. Let  $c(x)$  be the total cost incurred to produce  $x$  items. Economies of scale exist when  $c(x_1) + c(x_2) > c(x_1 + x_2)$ . This behavior is illustrated on the left-hand side of Fig. 2.4.

The opposite of economies of scale can also occur and are called *diseconomies* of scale. Here, the marginal cost increases with the volume of production. Generally, diseconomies of scale start to arise when congestion effects occur, that is, when there is no longer sufficient capacity to use available resources efficiently. This phenomenon is reflected in the rising curve on the right-hand side of Fig. 2.4. Economies and diseconomies of scale are often modeled using a power function

**Fig. 2.4** Economies and diseconomies of scale



**Fig. 2.5** Economies of scope



$c(x) = c^0 x^b$ , where  $c^0$  is a basic unit cost and the exponent  $b$  reflects the magnitude of the economies or diseconomies of scale. If  $b = 1$ , then  $c(x) = c^0 x$  and we fall back to the aforementioned linear variable costs. If  $b < 1$ , economies of scale exist; but if  $b > 1$ , there are diseconomies of scale. The parameters  $c^0$  and  $b$  are usually estimated using regression analysis.

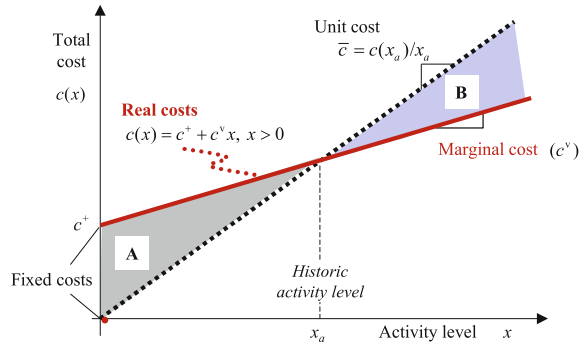
Economies of scope are generated when several products share the same resources (supervisors, equipment, IT systems, etc.). Let  $c(x_1, x_2)$  be the total cost for producing  $x_1$  and  $x_2$  quantities of two different products. Economies of scope exist when  $c(x_1, 0) + c(0, x_2) > c(x_1, x_2)$ . This behavior is illustrated in Fig. 2.5. Flexible modern technologies like robots are often a source of economies of scope.

### 2.2.1.3 Marginal and Unit Costs

As indicated above, accountants generally include a share of a company's indirect costs in their estimates of a product or activity's *unit cost*. Fixed costs are spread over all outputs produced. Suppose that the real activity costs can be described by



**Fig. 2.6** Marginal and unit costs



the function  $c(x) = c^+ + c^v x$  if  $x > 0$  (with  $c(0) = 0$ ) and that the level of activity observed over the last fiscal year was  $x_a$ , as illustrated in Fig. 2.6. In this case, the unit cost is obtained by dividing the total cost  $c(x_a)$  incurred during the fiscal year by the observed level of activity, giving  $\bar{c} = c(x_a)/x_a$ . *Marginal costs*, on the other hand, reflect the real cost incurred for an additional unit of activity. In the example, real costs are linear, meaning that the marginal cost corresponds to the variable cost, that is, to the slope  $c^v$  of the straight cost line. As can be seen in the figure, on the left-hand side of the activity level  $x_a$ , the unit cost as calculated underestimates the real total cost (region A). On the other hand, to the right of this point, the unit cost overestimates the real total cost (region B). In a planning process, a correct evaluation of total costs must be based on a cost function defined in terms of the decision variables involved (e.g., planned level of activity  $x$ ), while accounting for economies of scale or scope where this is relevant. Using unit costs to make decisions can lead to some major errors. For instance, a unit cost-based analysis might indicate that a product is not profitable and causes it to be abandoned. Yet if the calculations were based on marginal costs, it might become apparent that the product can increase the company's RCF. Having abandoned it, the indirect costs would be spread across fewer products, thus reducing the value created by the company!

### 2.2.1.4 Historic and Opportunity Costs

Accounting's factual focus demands the use of current costs or of an allocation of historic costs, such as depreciation for equipment. It remains that in a decision-making context, it is not the past that counts but the current and future impact of a decision. Hence, the need to rely on current or opportunity costs. The latter is a sacrifice associated with a particular decision. An example is the return that a company would have made on the sum invested in raw materials, semi-processed goods, and final products inventories had this capital not been tied up in stocks. Another is the revenues that could be obtained from leasing or selling a warehouse if the company was not using it.

### 2.2.1.5 Relevant and Sunk Costs

Not all of the costs that a company incurs are relevant for supply chain decision-making. A cost is considered relevant if it influences a decision in one direction or another. A simple example is deciding where to purchase a car model available from three dealerships. Assume the manufacturer sets the same sales price for all dealerships (say \$40,000), then this becomes irrelevant to the purchaser's decision—despite the large sum being spent. Relevant costs will then probably involve things like the distance that needs to be traveled to maintain the vehicle, plus any other service costs. On the other hand, if the dealers propose a different purchasing price, this becomes an important relevant factor in buyers' decisions. Thus, the idea of a relevant cost has nothing to do with the payment of a certain amount but reflects instead the way this might affect decision-making.

Sunk costs are an important category of irrelevant costs and involve expenses that have already been incurred by the company and do not have a direct effect on decision-making. For instance, a company may wonder whether it should keep or replace a piece of equipment. The costs that are relevant to this decision include the equipment's maintenance and operations expenditures; their current commercial value; and any tax aspects. On the other hand, the acquisition price paid several years ago for the current equipment is no longer relevant. Although this is often hard to accept, current assets' book value is seldom relevant to decision-making.

### 2.2.1.6 Operating Revenues and Expenses, and Capital Expenditures

Operating revenues and expenses are monetary flows associated with day-to-day activities. Operating expenses involve things like paying suppliers, employees, or energy bills as part of a company's primary or support activities. Operating revenues are linked to sales. Capital expenditures relate to a company's acquisition of long-term resources (facilities, equipment, vehicles, etc.). Although these strategic acquisition decisions involve an initial investment, owning long-term resources can also generate monetary inflows (tax repayments, residual value) as well as outflows (property taxes, insurance, etc.) throughout the assets' useful life.

In supply chain decision-making, it is often necessary to evaluate solutions (designs or plans) involving these three types of monetary flows across a single-period or multi-period planning horizon. For comparative purposes, revenues/expenditures must be linked to the decision variables specified for the time periods considered (e.g., merchandise flows between a factory and a DC during a year, opening a new factory at the beginning of a period, etc.). Relevant cash flows must be assigned to period costs/revenues in such a way to maintain their additivity over all the periods of the planning horizon. In general, the operating costs/revenues defined are derived from intra-period monetary flows. On the other hand, periodic capital costs are obtained by dividing supra-periodic commitments over several periods (typically years), which is usually not obvious. The breakdown must reflect the resources' commercial value over time, which may be quite

different from the book value obtained using normal accounting methods. The next section takes a closer look at this issue.

A good discussion of cost estimation assumptions and methods is found in Giard (2003). To conclude this section, it is worth emphasizing that supply chain decisions must be based on a calculation of relevant operating revenues/expenses and capital expenditures, and not on accounting conventions. The three following principles (Magee et al. 1985) should be kept in mind when analyzing strategic supply chain options:

- Costs must represent real out-of-pocket expenditures or profit opportunities that have been sacrificed.
- Only revenues/expenses and opportunity costs affected by the particular supply chain decisions made should be taken into account.
- It is more important to clearly capture the nature of all relevant revenues/expenses than to measure them precisely.

It is also crucial that double counting be avoided.

### 2.2.2 Discounting Cash Flows

When evaluating a strategic project, consideration must be given to all associated fund inflows and outflows during its useful life. Strategic investments provide assets lasting several years, which raises questions as to the value of money over time. Clearly, a sum invested today will produce interest and therefore be worth more in a few years. The opposite is also true. More specifically, when annual interest income is reinvested (compounded), \$1 invested at an annual interest rate of  $r$  will grow as shown in Fig. 2.7a). The growth term  $(1 + r)^t$  obtained after  $t$  years is called the *capitalization factor*. Similarly, the amount to invest to receive \$1 after  $t$  years can be determined retroactively as shown in Fig. 2.7b). The annual term  $(1 + r)^{-1}$  used in this calculation is called the *discount factor*. As a result, the *present value*  $V$  of a sum  $S$  received (spent) at the end of year  $t$  is

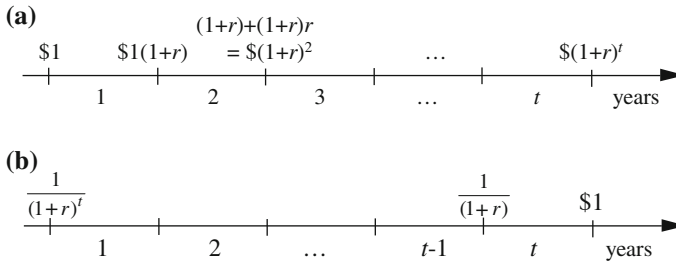
$$V = \alpha^t S, \quad \alpha = (1 + r)^{-1}$$

If the interest is compounded  $f$  times a year, the discount factor  $\alpha$  becomes

$$\alpha = \left( \frac{1}{1 + (r/f)} \right)^f$$

When the interest is compounded continuously, the discount factor becomes  $\alpha = e^{-r}$ , where  $e$  is the Neperian constant  $e = 2.71828\dots$

To evaluate a strategic project, the *net present value* (NPV) of all associated cash flows must be calculated, using the opportunity cost of capital instead of the annual



**Fig. 2.7** Value of \$1 in time under an annual interest rate  $r$

interest rate. This opportunity cost is referred to as the *discount rate*. The choice of an appropriate rate is a difficult problem that receives a great deal of attention in finance. Several issues may have to be considered to calculate this rate, including the company's capital structure, taxation, inflation, borrowing rates, insurance on borrowings, and financial risks. Studies in this area typically rely on simplistic assumptions that are crucial to whatever approach is being recommended. It is widely recognized, however, that two main categories of stakeholders should share a company's operating profits after tax, namely shareholders and creditors. In the following let:

- $r^S$  Return rate that shareholders expect to receive for comparable (notably in terms of risk) investments on the capital market
- $r^C$  Risk-free interest rate paid on the debt
- $\tau$  Corporate tax rate

The general recommendation is to use the weighted average cost of capital (WACC)  $r = \theta r^S + (1 - \theta)(1 - \tau)r^C$ , where  $\theta$  represents the proportion of capital employed that comes from shareholders. Since debt interest can be subtracted from a company's taxable income, the interest rate must be adjusted. Most companies have specific policies regarding the discount rate to use when choosing strategic projects, which is the assumption we make in the rest of this text.

If the initial investment (outflow of funds) associated with the project is  $S_0$ , and an inflow (outflow) of funds  $S_t$  occurs at the end of year  $t$  (an inflow being a positive monetary flow and an outflow a negative one), the NPV for the series of net annual flows  $S_0, S_1, \dots, S_T$  observed over a planning horizon of  $T$  years is

$$NPV = \sum_{t=0}^T \alpha^t S_t \quad (2.1)$$

A positive  $NPV$  signifies enrichment since the project provides a return superior to the cost of capital. Conversely, a negative  $NPV$  involves an impoverishment. Clearly, companies will only opt for projects producing positive  $NPVs$ .

Consider the case of a company deciding on whether to purchase a new equipment with an initial cost of \$100,000. It is forecasted that the net inflows of funds, over the next 3 years, resulting from this purchase will be \$30,000, \$35,000 and \$40,000. The equipment's resale value after 3 years is estimated at \$40,000. With the company using a cost of capital of  $r = 12.5\%$ , what is the NPV of the cash flows involved? This requires calculating NPV with (2.1) using  $S_0 = -100,000$ ,  $S_1 = 30,000$ ,  $S_2 = 35,000$  and  $S_3 = 40,000 + 40,000$ , with a discount factor  $\alpha = 1/(1 + 0.125) = 0.888$ , giving

$$NPV(\text{in } \$ 1,000) = -100 + 30(0.888)^1 + 35(0.888)^2 + 80(0.888)^3 = 10.257.$$

In other words, it is expected that the company will be enriched by \$10,257 if it purchases this piece of equipment.

A recurrent problem in practice is the choice between alternative investment projects with very different cash flows, useful lifespans, and residual values (the asset's value at the end of its useful life). It is important in these problems to compare projects on the same basis. Suppose that a company must invest in production equipment and that it is considering two options  $i = 1, 2$ . These options do not affect the products' sales price or actual sales, meaning that the only relevant cash flows are those relating to the equipment's purchase, operation, and maintenance. The data required to make a decision is thus the following:

- $S_{i0}$  Initial investment required for equipment  $i$
- $n_i$  Useful life of equipment  $i$  (in number of years)
- $RV_i$  Residual value of equipment  $i$  at the end of its useful life (can be negative)
- $S_{it}$  Total operating and maintenance expenses for equipment  $i$  during year  $t$

The net present cost  $NPC_i$  of each of these options is given by

$$NPC_i = (S_{i0} - \alpha^{n_i} RV_i) + \sum_{t=1}^{n_i} \alpha^t S_{it} \quad (2.2)$$

Suppose that  $n_1 < n_2$ . Basing our choice on the NPC's would not be fair due to the fact that  $NPC_2$  covers a longer period of time. To make the right decision, the options must be compared for the period of the shortest equipment's useful life ( $n_1$  in this case), and the cost calculations for option 2 must be revised. This can be illustrated with the data found in Table 2.1. This simplified example assumes that the expenditures  $S_{it}$ ,  $t = 1, \dots, n_i$ , are the same for each year of the equipment's useful life, and that the company uses a discount rate  $r = 6\%$  (and thus a discount factor  $\alpha = 1/(1 + 0.06) = 0.943$ ). The column  $(S_{i0} - \alpha^{n_i} RV_i)$  determines the equipment's present value in light of its residual value at the end of its useful life. The NPC's of the two options are calculated using relation (2.2). These values cannot be relied upon to make a decision due to the fact that  $NPC_1$  covers relevant

**Table 2.1** Example of choice between two pieces of equipment

$i$	$n_i$	$S_{i0}$	$RV_i$	$S_{i0} - \alpha^{n_i} RV_i$	$S_{it}, \forall t$	$NPC_i$
1	4	\$100,000	\$20,000	\$84,158.13	\$40,000	\$222,762.35
2	8	\$180,000	\$50,000	\$148,629.38	\$30,000	\$334,923.20

cash flows during the first 4 years, whereas  $NPC_2$  also includes expenditures in year  $t = 5, \dots, 8$ .

To make a valid comparison, the relevant annual cost of option 2 during the years  $t = 1, \dots, 4$  must first be evaluated. This is done by calculating the annuity required to recover, with interest, the initial value of equipment 2 during the 8 years of its useful life. Using the annuity calculation formula<sup>1</sup> (Crundwell 2008) leads to

$$AN_2 = (S_{20} - \alpha^{n_2} RV_2) \left[ \frac{r(1+r)^{n_2}}{(1+r)^{n_2} - 1} \right] = 148,629.38 \left[ \frac{0.06(1.06)^8}{(1.06)^8 - 1} \right] = \$23,934.67$$

Consequently, the annual investment and usage costs for equipment 2 during its first 4 years are  $AN_2 + S_{2t} = 23,934.67 + 30,000 = \$53,934.67$ ,  $t = 1, \dots, 4$ . The net present cost of the relevant cash flows is therefore

$$NPC_2(4 \text{ years}) = \sum_{t=1}^4 \alpha^t (AN_2 + S_{2t}) = 53,934.67 \sum_{t=1}^4 (0.943)^t = \$186,889.34$$

Since  $NPC_2(4 \text{ years}) < NPC_1$ , equipment 2 is the one that should be purchased. However, this analysis implicitly assumes that at the end of year 4, equipment 1 will be replaced by an identical machine. If this is not the case, an eight-year analysis considering the replacement equipment explicitly must be performed. As we shall see in Chap. 8, when several options are available over a given planning horizon, it is preferable to formulate the problem as a mathematical program.

A simpler approach to select an option would be to calculate the annuity needed to recover the capital invested, with interest, and the annual usage costs during the useful life of each piece of equipment. This is tantamount to calculating an annual *lease*  $L_i$  that should be charged for each option. These calculations are made using the following formula:

$$L_i = \left( \sum_{t=0}^{n_i} \alpha^t S_{it} - \alpha^{n_i} RV_i \right) \left[ \frac{r(1+r)^{n_i}}{(1+r)^{n_i} - 1} \right], \quad i = 1, 2 \quad (2.3)$$

The results obtained for the example are  $L_1 = \$64,287.32$  and  $L_2 = \$53,934.67$ . Since  $L_2 < L_1$ , the decision is the same as above. Note, however, that this approach

<sup>1</sup>With *Excel*, this calculation is done using the financial function  $PMT(r; n_2; \text{initial value})$ .

implicitly assumes that a more economical alternative than equipment 2 would not be available at the end of equipment 1's useful life. As Chap. 7 will show, when the company operates in a stable business environment, supply chain network design decisions are often taken using an optimization model defined for a typical year. Possible options are then assessed using this approach.

The preceding discussion neglects the effects of tax rebates. Equipment purchases can be amortized over several periods by applying the company's depreciation methods (linear, digressive, etc.) and applicable tax rules. As a result, it is possible with each option to recover taxes paid during the equipment's useful life. These cash flows are relevant to evaluate the options and they must be included in the analysis. Clearly, anticipated cash flows should also take inflation into account. Assuming, as we did, that the usage expenditures ( $S_{it}, t = 1, \dots, n_i$ ) will not change over the next 8 years is not very realistic. Each company operates within a specific context and investment decisions can be very diverse. Valid evaluations require substantial expertise in financial analysis.

Lastly, note that selecting investment projects based on NPV is not without flaws, in part because projected cash flows are random variables and not known quantities. To some extent, the discount rate can be selected to account for risk, but this ignores the fact that managers can modify their projects midstream, if necessary, to adapt to unexpected events. All sorts of *real options* (Trigeorgis 1996) such as delaying, abandoning, extending, or limiting the project exist in practice so that people can adapt to unforeseen events. The analysis should consider this. Several projects assessed as unprofitable when evaluated using NPV become profitable when real options are considered in the analysis.

### 2.2.3 SC Costs and Revenues

This section discusses the different costs and revenues that must be evaluated when trying to improve a company's supply chain system. All of these costs/revenues are inter-related in the sense that a decision taken to optimize one of them might increase or diminish others. Hence the importance of adopting a systemic approach, that is, one that seeks to maximize the value added by the supply chain. It has been explained that, conceptually, a company's value depends on the discounted sum of its RCF over its lifetime. Since cash flows can vary greatly over time, this definition does not facilitate the punctual estimation of value added in a given year. Periodic valuations can be done more easily using *economic value added* (EVA). These two notions (RCF and EVA) lead to equivalent definitions of value, which can be understood intuitively by examining them more closely. Let:

- $T$  Company's lifespan, in years
- $R_t$  Operating revenue of the company in year  $t$
- $C_t$  Operating costs of the company for year  $t$
- $\Delta I_t$  Company's net investment in assets during year  $t$  (net of asset sales)

$Dp_t$  Depreciation of company's assets for year  $t$

$Tx_t$  Tax paid by company for year  $t$

The value of the company  $V^E$  expressed in terms of RCFs ( $RCF_t$ ) for years  $t = 1, \dots, T$ , is given by the following expression:

$$V^E = \sum_{t=1}^T \alpha^t RCF_t, RCF_t = (R_t - C_t - Tx_t) - \Delta I_t, Tx_t = \tau(R_t - C_t - Dp_t) \quad (2.4)$$

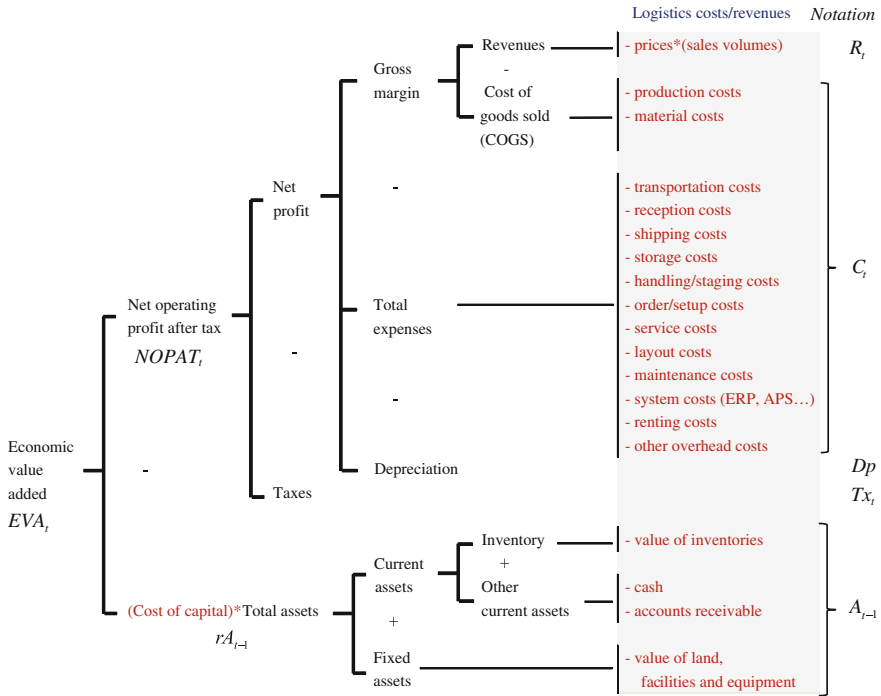
The company's investment  $\Delta I_t$  in year  $t$  is linked to its set  $M_t$  of long-term assets and to variations in current assets. The long-term resources  $i \in M_t$  in use come from past investment projects. As shown above, each of these investments can be converted into a series of annuities covering the useful life of the resource. For a year  $l$  of the useful life of asset  $i \in M_t$ , the annuity calculated can be separated into two parts: the asset depreciation  $Dp_{il}$  during the year, and the opportunity cost of capital  $r\bar{Dp}_{il-1}$ ,  $\bar{Dp}_{il-1}$  being the remaining (non-depreciated) part of the initial investment. Sorting these amounts by years and cumulating them produces the depreciation  $Dp_t = \sum_{i \in M_t} Dp_{it}$  and the non-depreciated value  $A_{t-1} = \sum_{i \in M_t} \bar{Dp}_{il-1}$  of assets at the beginning of year  $t = 1, \dots, T$  (Shrieves and Wachowicz 2001). Finally, by substituting into (2.4), the following expression is obtained:

$$\begin{aligned} V^E &= \sum_{t=1}^T \alpha^t EVA_t, \quad EVA_t = [(R_t - C_t - Dp_t) - Tx_t] - rA_{t-1} \\ &= (R_t - C_t)(1 - \tau) - [(Dp_t + rA_{t-1}) - \tau Dp_t] \end{aligned} \quad (2.5)$$

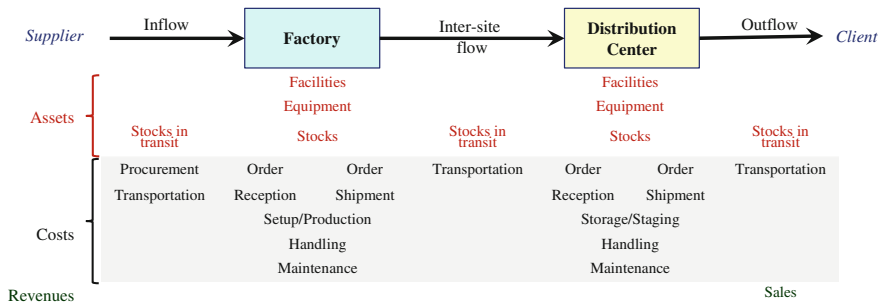
The relationships between the economic value added  $EVA_t$  defined in (2.5) and the revenues, expenditures, and assets of a supply chain system are represented in Fig. 2.8. Operating costs and revenues are generated by primary activities affecting products in time (storage), space (transport and handling) and form (production), by transactions with business partners (purchases, sales), and by support activities like maintenance and quality control. The cost of assets are calculated by multiplying the value of the company's assets  $A_{t-1}$  (land, facilities, equipment, inventory, and other current assets) by the cost of capital  $r$ . Figure 2.9 shows how these costs and assets associate with material flows and resources in a simplified supply chain system. This section will study the supply chain revenue and cost functions required to calculate  $EVA_t$ , particularly those associated with cost  $C_t$ , annuity  $(Dp_t + rA_{t-1})$ , and tax savings  $\tau Dp_t$ .

Before studying the costs/revenues associated with the material flows, inventories, and resources identified in Fig. 2.9, it is important to distinguish between those required for the short-term operational decision-making (quantities to be ordered, manufactured, delivered, and stored in the immediate future), as opposed to the long-term strategic decision-making. Towards this end, let us examine factory-specific production decisions for a set of products, considered as an





**Fig. 2.8** Impact of revenues, costs, and supply chain assets on value creation



**Fig. 2.9** Main assets, costs, and revenues in a supply chain system

aggregate product family for strategic decision-making. Assume that  $m_p$  lot-sizing decisions are made for product  $p$  during a year, and define the following activity variables:

- $Q_{pj}$  Lot size for product  $p$  resulting from production decision  $j$  ( $j = 1, \dots, m_p$ )
- $X$  Aggregate quantity of products manufactured during the year for the product family

When these operational and strategic decision variables are all expressed using a standard load unit (e.g., a pallet), we have that

$$X = \sum_p \sum_{j=1}^{m_p} Q_{pj} \quad (2.6)$$

Assuming that the production cost function for product  $p$  is  $c_p^P(Q)$ , the aggregate annual production cost is given by

$$C^P(X) = \sum_p \sum_{j=1}^{m_p} c_p^P(Q_{pj}) \quad (2.7)$$

However, for strategic decision-making,  $C^P(X)$  must be expressed in terms of  $X$ , and not as an implicit function of operational lot-sizing variables  $Q_{pj}$ . This transformation can be extremely complex, and even impossible, especially if  $c_p^P(Q)$  is not linear.

Two approaches may overcome this obstacle. One consists of calculating an aggregate unit cost for product  $p$  using historic production decisions  $Q_{pj}^o$ ,  $j = 1, \dots, m_p^o$ , for a recent year. This leads to

$$C^P(X) = \bar{c}X, \quad \bar{c} = \sum_p \sum_{j=1}^{m_p^o} c_p^P(Q_{pj}^o) / \sum_p \sum_{j=1}^{m_p^o} Q_{pj}^o \quad (2.8)$$

The advantage of this function is that it is linear, but it does suffer from all of the aforementioned unit cost flaws, and it hides economies of scale and scope. An alternative consists of cumulating relevant fund outflows over a typical year, and establishing a relationship between these cumulative expenses and the aggregate production variable  $X$ . When responsibility centers with the same mission in a company apply the same methods, several distinct observations can be obtained and regression analysis can be used to estimate the  $C^P(X)$  function. The paragraphs below will show how this approach can be exploited to evaluate different aggregate supply chain cost functions.

### 2.2.3.1 Cost of Adding, Transforming, Using, or Withdrawing Long-Term Resources

When a building is bought to house a factory or distribution center, it is expected that the sum invested will be recovered later from the revenues generated by the building's activities. This reasoning applies not only to the acquisition of a building, but also to the renovation of a facility or to the construction of a new production–distribution center. It also applies to the acquisition/overhauling of production,

storage, transportation, or handling equipment. Section 2.2 on discounted cash flows (and the examples it includes on choices between different types of equipment) offers a facility/equipment selection methodology. A few more precisions may be useful, however.

First note that the resources of a supply chain system are often leased or rented and not purchased. Some leasing contracts also enable the acquisition of the facility/equipment after a certain time. Leasing offers certain advantages as follows:

- Companies often consider leasing costs as operational expenditures, which may offer tax advantages and improve certain financial ratios;
- Initial outlays are generally relatively low compared to the value of the good;
- The risk of obsolescence may be reduced;
- Contracts can be adapted to particular situations (like seasonal variations);
- Equipment can be tried out before the purchase, and the project can be abandoned;
- The financing of the investment is the responsibility of the owner.

Among the shortcomings, the full and final cost of a lease can be high. Also, it often leaves the lessee with less room to maneuver in terms of how the resource might be used.

Modifying a supply chain system's long-term resources amounts to a change of state, and the costs incurred depend on the state of the system before the investment or lease takes place. Several situations are possible, and Table 2.2 shows the annual cash flows associated with each. Closing costs can be high when a production or distribution center's operations are stopped. In addition to moving costs, penalty costs are typically incurred including severance packages for departing personnel, the reimbursement of subsidies received, crisis management expenses, and even revenues lost due to dissatisfaction with the decision. On the other hand, where the asset has substantial commercial value, there is a possibility that it can be recovered. If a facility/equipment in place continues to be used, an opportunity cost equal to its commercial value multiplied by the company's cost of capital is incurred. Conversely, if a new factory is being built or an existing one is being purchased and renovated, as discussed above the annuity needed to recover the sums invested during the factory useful life must be calculated. An intermediary situation involves enlarging or renovating an existing building. This kind of project can also involve significant reorganization costs (moving equipment or inventory, installation of IT systems, staff training, etc.) that add nothing to the assets' commercial value. As such, they are operating expenditures that will be disbursed only once when the asset's state changes. Other fixed operating costs associated with ownership of assets—such as heating, insurance, maintenance, and security—are incurred annually.

Overall, the cost function  $C^R(\cdot)$  associated with the addition, transformation, usage, or withdrawal of a long-term resource includes a combination of fixed operating expenses and asset ownership costs that do not all have the same fiscal impact. The definition of EVA given in expression (2.5) provides the key to determine how they should be accounted for.

**Table 2.2** Examples of the costs of changing the state of long-term resources

		Strategic decision		
<i>Initial state</i>		<i>Not using the resource</i>	<i>Continue using the current resource</i>	<i>Using a new resource</i>
Current resource	<i>Fixed asset</i>	– Closing cost – Recovery of commercial value	– Opportunity cost – Fixed operating cost	– Annuity – Opportunity cost – Layout cost – Fixed operating cost
	<i>Lease</i>	– Closing cost – Breach of contract penalty	– Lease – Fixed operating cost	– Lease – Layout cost – Fixed operating cost
Potential resource	<i>Build</i>	Nil		– Annuity – Layout cost – Fixed operating cost
	<i>Buy and renovate</i>	Nil		– Annuity – Layout cost – Fixed operating cost
	<i>To lease</i>	Nil		– Lease – Layout cost – Fixed operating cost

### 2.2.3.2 Inventory Costs

Inventories are inevitable in a supply chain. Whether products are moved within one site (handling) or between sites (transportation), *stocks in transit* are immobilized during the duration of the journey. If products are ordered or manufactured in batches and these batches are not consumed instantly when received/produced, *cyclical stocks* exist during the period of consumption. When demand cannot be forecasted with certainty, *safety stocks* must be kept to avoid shortages. When demand is seasonal but it is not possible to modulate production capacity over the course of the year (due to collective agreements for instance or because the processes are too complex), production must be smoothed thus generating *seasonal stocks*. When raw material prices are volatile, it can be advantageous to invest in *speculative stocks*. If quantity discounts are available, or if substantial savings can be achieved by hauling full loads, it can be advantageous to consolidate purchases/shipments, leading to *scale stocks*. When the supply chain system is vulnerable to natural catastrophes, *insurance stocks* may be worth keeping.

Inventory *holding costs* combine all the costs of keeping inventory over time, thus all relevant costs that vary depending on stock levels. The costs incurred for keeping an item in stock over the course of a year is generally expressed as a

percentage of the product value. The unit holding cost is calculated by multiplying this rate by the item's value. For instance, if the rate used is 18 % per annum and if the item is valued at \$200, the holding cost is  $0.18(200) = \$36$  per item per annum. Charges incorporated into the calculation of the holding cost can be grouped into four categories: cost of capital, cost of service, cost of risks, and cost of using space. The cost of capital was discussed above, and most companies have their own policy in terms of which rates to use. Stocking items literally immobilize funds that could be invested elsewhere. This is clearly an opportunity cost.

Service costs include expenditures that are incurred to protect stocks, for instance, by insuring them. Other expenses, like cyclical inventory counting or taxes on stocks levied in some states, also come under this category. Companies in Québec (Canada), for instance, must pay taxes on assets, hence on inventories. Risk-related costs are associated with undesirable events that can happen when a company keeps inventories. These can include damage, theft, and obsolescence. Fashion items and perishables are particularly vulnerable to obsolescence. All of these costs can be represented as percentages if they are added up for a given year and divided by the average value of the stocks being held. Lastly, the cost for using warehousing space reflects warehouses' operating expenses. Not all of these costs are relevant. For instance, heating, electricity, and security costs are rarely relevant because they do not vary depending on stock levels. Reception, handling, and shipping costs are also independent of stock levels because they depend on the volume of orders received and issued. If a public warehouse is being used, the amount billed for space rises with stock levels and is therefore relevant. If the space occupied in a private warehouse can be used for other purposes, an opportunity cost is incurred. When calculating the final rate to apply, one must be careful to avoid double counting.

Once the inventory holding cost rate has been established, the annual inventory holding cost  $C^I(\bar{I})$  of a product in a supply chain network node or arc can be calculated as follows:

$$C^I(\bar{I}) = (r^I v) \bar{I} \quad (2.9)$$

$r^I$  Inventory holding cost rate (in \$/\$/year)

$v$  Value of the product kept in stock (including value added upstream in the network)

$\bar{I}$  Average inventory level during the year

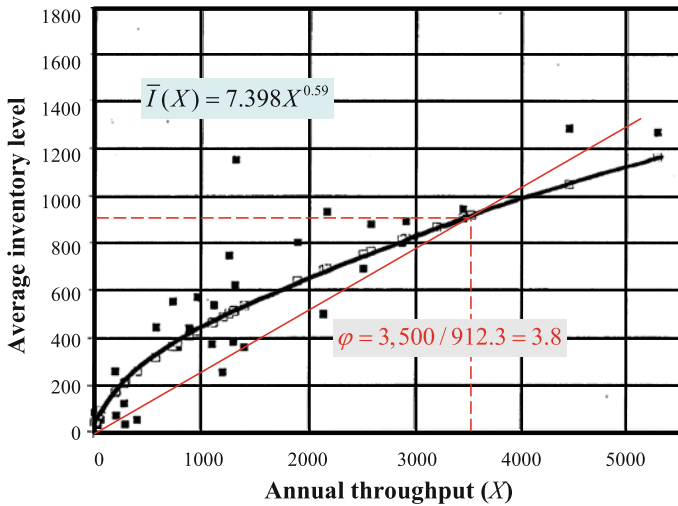
In inventory management, the average inventory  $\bar{I}$  incorporates cyclical stocks associated with the procurement lot size  $Q$  as well as safety stocks based on the variance of the demand  $\sigma_{LT}^2$  during a delivery lead time (LT). For traditional (min, max) inventory control systems,<sup>2</sup> the average level of cyclical stocks is  $\bar{I}_C = Q/2$

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<sup>2</sup>The *min* is an order point and the *max* a replenishment level.

and the safety stock is  $\bar{I}_{SS} = \kappa \sigma_{LT}$ , where  $\kappa$  is a safety factor reflecting the required service level (Silver et al. 1998). The value of  $Q$  depends on the company's inventory management methods and demand levels.  $Q$  is often calculated using the economic order quantity formula  $Q = (2q\bar{x})^{0.5}$ , where  $\bar{x}$  is the average annual demand and  $q$  the ratio of fixed order cost over holding cost. It has been shown that the standard deviation of demand during a delivery lead time can be evaluated approximately using the formula  $\sigma_{LT} = a_{LT}\bar{x}^{b_{LT}}$ , where  $a_{LT}$  and  $b_{LT}$  are empirically estimated regression coefficients. As a result, when the company's inventories are well managed, an empirical relationship of the form  $\bar{I} = a\bar{x}^b$  can be established between the level of cyclical and safety stocks, on the one hand and demand, on the other hand.

Strategic decisions relating to supply chain network design must assess inventory holding costs for all the storage points in the networks considered. The annual demand for a storage point, in this context, corresponds to its product's throughput  $X$ , this throughput being one of the variables to be optimized. From the discussion above, it follows that, for a given family of products held in a storage point, an empirical relationship  $\bar{I}(X) = aX^b$  can generally be established between the average inventory level and the annual throughput  $X$ . Figure 2.10, for instance, illustrates the concave inventory–throughput function estimated for the electric poles held in the storage points of an electricity distributor. This function was estimated using regression analysis, from a set of observations corresponding to historic average inventory and annual throughputs for the company's storage points. For a given historic throughput  $X^o$ , the ratio  $\varphi = X^o / \bar{I}(X^o)$  corresponds to the inventory turnover ratio. For the poles example, a storage point with an annual throughput of 3,500 poles has an inventory turnover ratio  $\varphi = 3500 / (7.98(3500)^{0.59}) = 3.8$ .



**Fig. 2.10** Inventory–throughput function for poles stored by an electricity distributor

Substituting the estimated function  $\bar{I}(X)$  in (2.9) produces the following holding cost function:

$$C^I(X) = (r^I \bar{v}) a X^b \quad (2.10)$$

where  $\bar{v}$  is the average value of the items in the product family being considered. This storage cost curve reflects the economies of scales that can be achieved by using large distribution centers in a supply chain network. Note that, as illustrated in Fig. 2.10, the historic inventory turnover ratio  $\varphi$  can be used to linearize this function, giving  $C^I(X) \approx (r^I \bar{v} / \varphi) X$ . This linear function suffers, however, from all of the defects associated with the use of unit costs, without, of course, capturing the economies of scale.

To conclude this section, it is worth noting that stock-outs in a supply chain network can also generate opportunity or recourse costs. Stock-outs can lead to either lost sales or backorders (late deliveries). The cost of a lost sale not only includes the margin forgone on the sale but also the NPV of all future contributions to profits lost because of eroded goodwill. This cost is generally very difficult to estimate. Similar costs also arise with backorders. In some cases, emergency measures can be adopted to avoid lost sales or backorders. These recourses can assume different forms: prioritizing an order in the scheduling system, using overtime to increase output, paying for priority shipping services, etc.

### 2.2.3.3 Transportation Costs

Transportation costs are what a company spends to move materials between different sites in its supply chain network. The mode of transportation and type of transporter used affects these costs. Companies can operate their own vehicle fleet but this involves investment outlays (vehicles and garages), fixed operating costs (maintenance, insurance, permits), and variable costs (drivers, fuel, tires, repairs). Table 2.3 provides a breakdown of the annual cost of trucking in the United States.

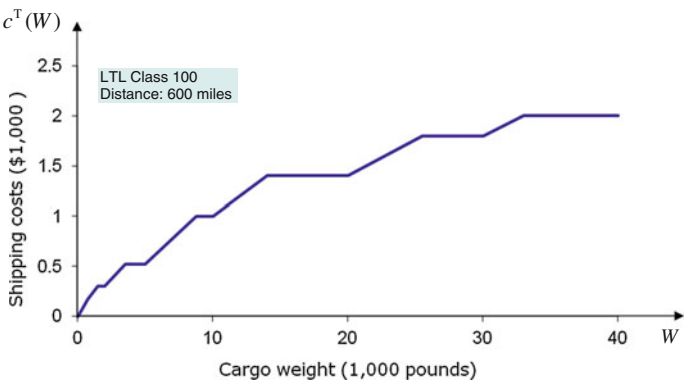
Companies can also choose to work with third-party transportation services providers, and transportation costs then depend on the tariffs charged. For road transport, small loads are typically shipped on a less-than-truckload (LTL) basis whereas larger loads are shipped in full truckloads (TL). It is generally possible to achieve significant economies of scale (depending on the load size) for a given origin–destination lane and merchandise type. The typical structure of LTL transportation tariffs is illustrated in Fig. 2.11. Cargo size is generally expressed in kilograms (kg) or hundredweight<sup>3</sup> (cwt). The shipment weight obviously depends on the quantity  $Q_p$ , of product  $p$  being transported, and on the weight  $w_p$  of a unit load. The transportation cost function  $c^T(W)$  depends on the total weight being

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<sup>3</sup>In North America a hundredweight is equal to 100 pounds (*short* hundredweight) and in Britain to 112 pounds (*long* hundredweight).

**Table 2.3** The real cost of a commercial truck in the United States in 2011—*Source* The Truckers Report (2015)

Cost elements	Total cost/year	Cost/mile	Proportion (%)
Truck cab and trailer (amortized over 5 years)	\$30,600	\$0.24	17
Fuel (20,500 gallons a year)	\$70,200	\$0.54	39
Driver salary	\$46,800	\$0.36	26
Maintenance and repairs	\$15,000	\$0.12	10
Insurance	\$6500	\$0.05	4
Tires	\$4000	\$0.03	3
Permits, licenses and tolls	\$3600	\$0.02	2
Total	\$180,000	\$1.38	100



**Fig. 2.11** Transportation costs as a function of load

shipped  $W = \sum_p w_p Q_p$ . The function is piecewise linear with a gradually decreasing slope to reflects the fact that as the load increases, it becomes possible to use more efficient handling/transportation means. Tariff structures are different for air, rail, road, and maritime transportation, but economies of scale are usually present. Chapter 5 studies the characteristics of these different transportation modes.

Design decisions usually require the estimation of supply chain network’s transportation costs. In this context, the focus is on the costs generated on network arcs by the annual flow  $F$  of a product family. The situation is similar to the one described above for Eqs. (2.6) and (2.7). If the size of the transportation loads is predetermined (e.g., a full truckload), the cost for a load is fixed and transportation costs  $C^T(F)$  can be reasonably evaluated using a unit cost  $\bar{c}$  based on historic data, as done for (2.8), or directly reflecting transportation company tariffs. Conversely, when shipping frequencies are fixed (fixed production cycles, fixed delivery schedules, etc.), the size of the loads being shipped depends on  $F$ . More



specifically, assume that  $E$  shipments are made every year. This means that  $W = (F/E)\bar{w}$ , where  $\bar{w}$  is the average weight of a product. The resulting transportation cost function is  $C^T(F) = Ec^T(\bar{w}F/E)$  and it is not linear. As part of a long-term transportation contract negotiation, volume discounts could also be offered on the annual flows  $F$  on an arc or on a subset of the network's arcs.

#### 2.2.3.4 Throughput Costs in Facilities

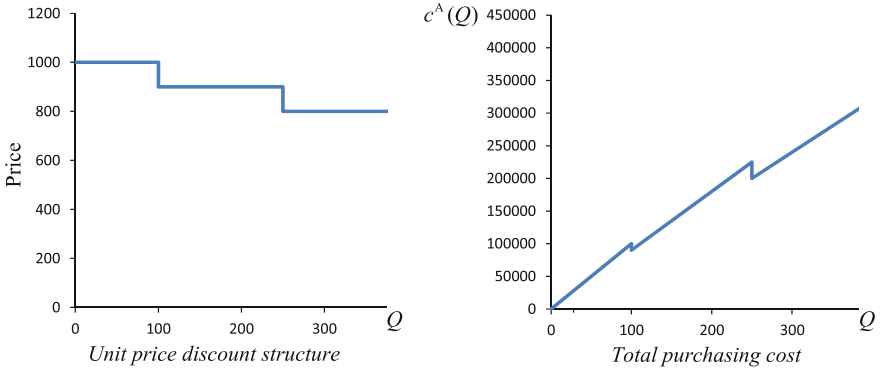
Another important aspect of an SCN design is the costing of production–distribution centers' activities. As illustrated in Fig. 2.9, the following are the main activities performed in these centers:

- Issuing orders to internal or external upstream suppliers, leading to reception, inspection, handling (between storage, production or shipping points) and storage activities;
- Receiving orders from internal or external downstream customers, leading to picking, handling, staging, shipping and service activities;
- Production/assembly of components/products, which usually involves upstream and downstream handling activities.

For discrete products, these activities lead to periodic lot-sizing decisions, which generate setup costs and variable execution costs. There are also a number of indirect costs, relating, for instance, to supervision and maintenance.

At an operational level, when a batch  $Q$  of products is ordered or manufactured, the variable costs generally incorporate material purchase, direct labor and energy consumption charges. In a production context, fixed costs include tooling and setup expenses. In a procurement context, they include order preparation, transmission, tracking, reception, inspection, and payment expenses that are independent of  $Q$ . If the company manages several facilities, regression analysis can be used to estimate this fixed ordering cost, with the facilities annual purchasing expenditures being the dependent variable and the number of orders issued the independent variable. The slope of the regression line obtained provides an estimate of the ordering cost. Note that the operational activity cost function  $c_p(Q)$  for a product  $p$  is not necessarily linear. If, as discussed above, different equipment can be used to make a given product, the unit production cost for each piece of equipment will differ. Consequently, when rules are elaborated to specify the equipment to use for the production of different quantity  $Q$  of products,  $c_p(Q)$  will likely be a concave function.

At the strategic level, for a plant, the aggregate annual throughput  $X$  of a product family is usually related to production decisions, as shown in (2.4), and what needs to be done to estimate an aggregate production cost function  $C^P(X)$  was already discussed. For distribution centers, the throughput  $X$  reflects either aggregate inbound receptions or outbound shipments, which, on a yearly basis, should be roughly equal. This requires the estimation of an aggregate throughput costs function  $C^D(X)$  encompassing all relevant reception, handling, and shipment



**Fig. 2.12** Quantity discounts example

expenses. This function should reflect fixed lot-sizing costs as well as variable operational costs. Lastly note that as annual flows increase, it becomes possible to use better performing production/storage/handling technologies, occasioning possible economies of scale.

### 2.2.3.5 Purchasing and Sales Prices

Purchasing price structures are often complex because of quantity discounts, temporary low prices, or payment conditions. A typical quantity discounts example is illustrated in Fig. 2.12. The acquisition cost function  $c^A(Q)$  represented is piecewise linear. If the price charged by the supplier for a product does not vary over time or as a function of the lot size  $Q$  being ordered, it is not relevant to the procurement decision. However, it is relevant if one has to choose between different supply sources. There are also situations where discounts are based on the annual purchase volume  $X$ , especially in contexts where supplies are provided through long-term contracts. Negotiating and managing this type of contract, however, does generate fixed costs. This being the case, the acquisition cost function  $C^A(X)$  to use at the strategic level is usually concave and often piecewise linear.

This discussion was presented from a procurement prices perspective, but it also applies to the prices that companies charge customers for products sold. Sales price structures can be described by unit price functions  $\pi(Q)$  and revenue functions  $R(X)$  similar to the acquisition costs functions in Fig. 2.12. It is clear that these functions may also depend on other order winners like response times or service levels. An appropriate pricing policy can be a source of considerable additional revenues due to its impact on unit margins or market share.

## 2.3 Value Creation

We studied costs and revenues relevant to the optimization of supply chain networks. The total cost of a company's supply chain system depends on the nature of its primary activities, its planning and control processes, and the structure of its supply chain network. Chapter 1 discussed the processes and structures of supply chain systems in detail. We have also seen that the market share of a company, and ensuing revenues, generally depends on the order-winning attributes (price, quality, response times, flexibility, coverage, availability, etc.) the supply chain system can offer to potential customers. Mastering these concepts is important to value creation. The present section examines *value chains* and it shows how value creation results directly from the minimization of total supply chain costs and the elaboration of order winners that maximize corporate revenues. Figure 2.13 illustrates the impact of a supply chain network structure on the cost of value-creating activities and on response time, an order winner favored by world-class customers. Much of the following discussion relates to this figure.

### 2.3.1 Corporate Value Chain

The first chart in Fig. 2.13 describes how costs accumulate at each stage of a simple production–distribution network, thus forming a *value chain* (Porter 1985). The symbols used to describe the stages are the same as in Fig. 1.8. The chart shows how raw materials, production, warehousing, transportation, and storage costs relate to primary activities. The relation between the cost functions previously discussed and the cost added at each stage of the supply chain is illustrated using the notation introduced above. Support activity costs, long-term resource costs, and taxes are also added to obtain the total system cost.

The chart also illustrates the definition of EVA displayed in Eq. (2.5). It is worth emphasizing that the value chain is a snapshot of the situation of a company at a particular point in time. If the company alters supply contracts, if it adopts new production–distribution technologies, if it changes transportation means or if it modifies planning and control processes, the total system cost curve will change. Even if none of these elements is modified during a given time period, the cost curve can change due to learning phenomena.

#### 2.3.1.1 Response Times and Inventory

Fig 2.13's second chart illustrates the relationship between a company's response times, the types of inventory it keeps (finished products, semi-processed goods, raw materials), and where it is positioned (in a factory, national/regional DC or store) in relation to the marketplace. As Chap. 1 discussed, the first inventory location in a

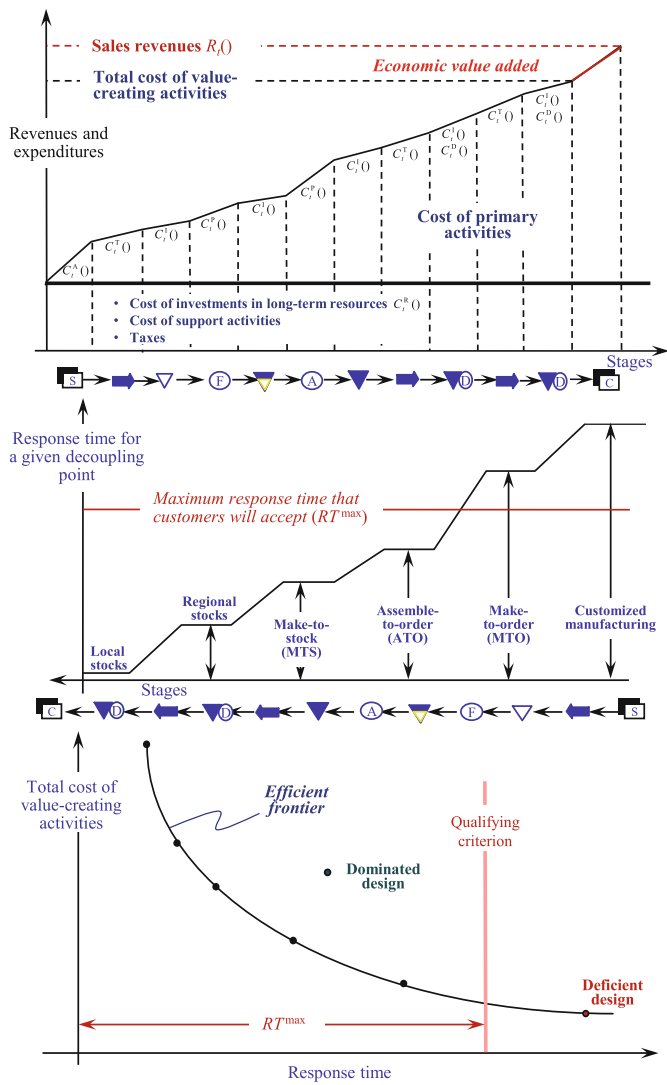


Fig. 2.13 Value chain and efficient frontier

supply chain is a *decoupling point* that determines response times. The closer a company keeps its stocks to customers, the shorter its response times. When a stock of finished products is kept locally, delivery times can be very short. On the other hand, if no inventory is kept (customized manufacturing) the delivery times will necessarily be longer, even if efficient and flexible production technologies are used. For a given company, the best supply chain strategy (local/regional stocks vs make-to-stock vs make-to-order, etc.) depends on several factors discussed below. Clearly, customer

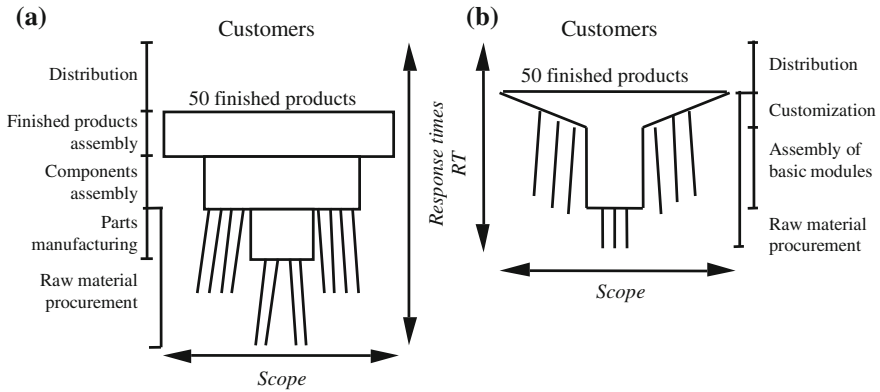
expectations are paramount. If the total customer order-to-delivery cycle time under a given strategy (say, make-to-order) is longer than the maximum response time  $RT^{\max}$  that customers require, this deficient strategy cannot be used. For consumer goods like grocery, inventories must be kept in-store to ensure satisfactory service.

This raises questions about the role inventories play within a supply chain network. In just a few years, industry has gone from using inventories as a protection against all system defects to considering them as a calamity to be avoided at any price. It is true that inventories should not be used as a remedy for all system defects because, as claimed by partisans of the *zero-stock* paradigm, this hides operational problems and inhibits their solution. It is just as clear, however, that in certain contexts, inventories can create value. The zero-stock target can only be approached if there is no uncertainty about future demand and procurement/production lead times, and if demand is relatively stable. This is difficult to imagine, for instance, in the retail trade. Uncertainty and variability can be reduced by working on the environmental factors that create them (through strategic alliances with customers, suppliers, subcontractors, and third-party logistic providers, for example), but they can rarely be eliminated.

### 2.3.1.2 Efficient Supply Chain Networks

The first two charts in Fig. 2.13 reveal the impact of the structure of a supply chain network on costs and response times. Any potential SCN design is characterized by value and response time curves of this type. Each of the points on the third chart of Fig. 2.13 specifies the total cost and response time associated with a possible design. The line joining the points (designs) not dominated simultaneously on the cost and response time axes form an *efficient frontier*. This implies that several potential SCN designs (possibly including the status quo) are inefficient. For instance, a MTO supply chain using air freight to deliver massive low value products is unlikely to be efficient. The form of the efficient frontier depends on several factors, not all of which are controlled by the company. Before examining the impact of these factors, two important observations must be made, however. On the one hand, not all efficient designs are necessarily valid. For instance, the design to the right of the efficient frontier is defective because it does not enable the  $RT^{\max}$  response time that customers require. On the other hand, all the designs on the efficient frontier respecting qualifying criteria provide a value-creating posture. Other elements, such as the curve's shape and the response times' impact on revenues, must be examined to reach a final decision.

The shape of the efficient frontier is influenced first by the nature of the products being manufactured/distributed and by the company's industrial environment. The value/weight ratio of the products sold has a crucial effect. A high value product that is light and not very voluminous (jewelry, electronic instruments, etc.) is expensive to stock but can be transported quickly for little cost. Conversely, a low value product that is heavy and voluminous (paper, cement, etc.) is expensive to transport but it can be held in inventory without incurring excessive costs.



**Fig. 2.14** Bill-of-material (BOM) of an assortment of products

Risks associated with the business environment and particularly with the variability of demand also have a significant effect. Where demand is stable and foreseeable, it is possible to provide a good service with very low inventory levels.

Most of the elements in a company's supply chain strategy described in Fig. 1.14, also affect the shape of the efficient frontier. Improvements in sourcing, production/distribution technologies, transportation means, or planning and control system push the efficient frontier to the bottom left. The scope of the assortment of products sold and the form of their bill-of-material (BOM) are also crucial. Figure 2.14 illustrates two extreme cases. The BOM on the left reflects the assembly of finished products from different components incorporating several distinctive parts. This results in very long response times and a need for highly diversified manufacturing, assembly, and sourcing processes. On the other hand, the BOM on the right looks like a mushroom. Here, the finished products are assembled at the very end of the process, using only a limited number of modules. Reducing components' variety makes it possible to manufacture modules in focused factories located where production factors are most advantageous, and it mitigates the negative impacts of uncertainty. This type of BOM leads to flexible supply chain networks with much shorter response times.

The repartition of the costs and response times associated with primary activities along the supply chain also affects the efficient frontier. Since inventory holding costs increase at each stage of the supply chain network (due to the value added during the preceding stages), it is desirable to keep inventory (if needed) before stages that add substantial costs, especially if this does not increase response times significantly. In addition, the value added at a particular stage depends on the economies of scale and scope associated with the technologies being used. Some technologies require significant initial investments (e.g., assembly lines) but they significantly lower marginal production costs. This provides a good reason for concentrating (focusing) production of all products/components requiring similar technological systems in a single facility, which also facilitates learning. When the

BOM is mushroom-shaped (Fig. 2.14b), locating final assembly operations close to the final market enables excellent response times. Economies of scale are also enhanced when components production is concentrated in a few focused factories.

### 2.3.2 Choosing the Design Maximizing Value Creation

Fig 2.13 shows that the structure of an SCN has a significant impact on two primordial order winners: low prices (via low costs) and quick responses. These are however not the only value criteria to consider (see Table 1.1) and the impact of all order winners on revenue generation is crucial to the final decision. Most order winners depend on the structure of the supply chain network, and the notion of an efficient frontier can be extended to analyze their impact on value creation. As illustrated in Fig. 2.15, the order winners offered by a company affect its revenues and costs, and consequently the value added by its supply chain network. When engaged in a SCN reengineering project, a company should therefore select the design maximizing long-term value creation, that is

$$V^{\text{SCN}} = \max V^{\text{SCN}}(RT) = \sum_{t=1}^T \alpha^t EVA_t^{\text{SCN}}(RT), \quad (2.11)$$

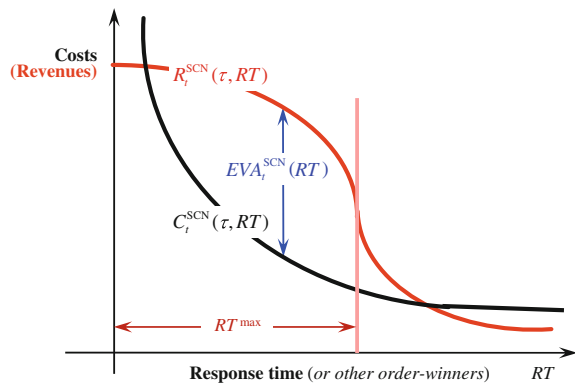
$$EVA_t^{\text{SCN}}(RT) = R_t^{\text{SCN}}(\tau, RT) - C_t^{\text{SCN}}(\tau, RT) \quad (2.12)$$

$$R_t^{\text{SCN}}(\tau, RT) = (1 - \tau)R_t^{\text{SCN}}() \quad (2.13)$$

$$C_t^{\text{SCN}}(\tau, RT) = (1 - \tau) \sum_{PA} C_t^{PA}() + \sum_{LTR} C_t^{LTR}(\tau, ) \quad (2.14)$$

In these expressions, the label SCN (Supply Chain Network) is used to indicate that in a reengineering project, the only cash flows to consider are relevant revenues

**Fig. 2.15** Economic value added for a given period



and costs, and not all the company's inflows and outflows as in (2.5). The value is calculated over the planning horizon of  $T$  years considered in the design project. In the definition of  $EVA_t^{\text{SCN}}(RT)$ , the revenue and cost functions,  $R_t^{\text{SCN}}(\tau, RT)$  and  $C_t^{\text{SCN}}(\tau, RT)$ , depend on  $\tau$  since tax effects must be considered. In expression (2.14), the index  $PA$  denotes the network's *primary activities*, and the costs  $C_t^{PA}()$  correspond to the generic functions defined above for purchases, stocks, transportation, production, and throughputs (see the top chart in Fig. 2.13). The  $LTR$  index represents the network's *long-term resources* with  $C_t^{LTR}(\tau, )$  referring to the generic cost function  $C^R()$  defined above. The  $LTR$  cost is a function of the tax rate  $\tau$  since it must account for the tax reductions obtained for the ownership of resources.

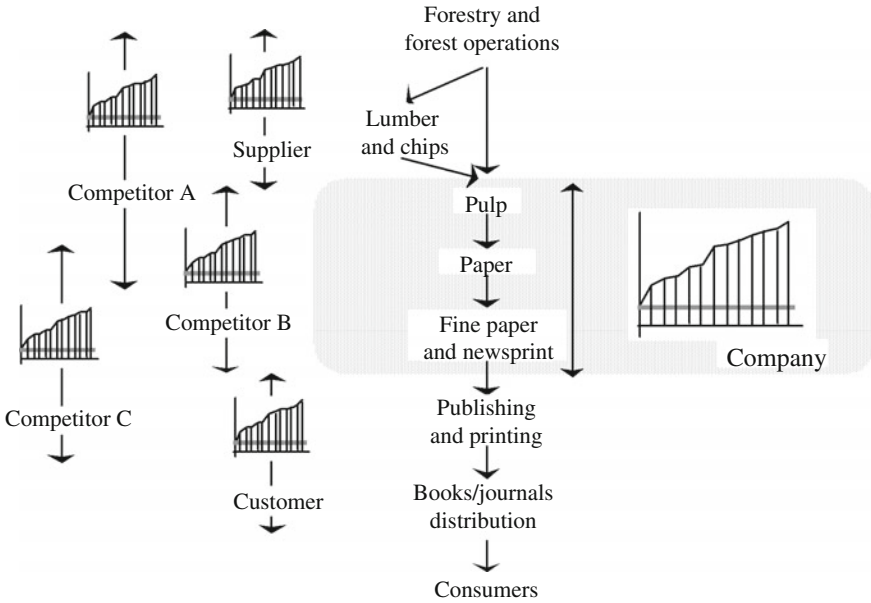
The total sales revenue curve  $R_t^{\text{SCN}}(\tau, RT)$  provides the value that customers attach to the response times (and to other network-dependent order winners price, flexibility and service) given by the efficient SCN designs. Note that the shape of this curve reflects the fact that beyond a certain response time  $RT^{\text{max}}$ , there is a sharp decline in customer interest. When delays are too long, if the company does not cut prices, demand and revenues decline. If it cuts prices, market shares may be preserved, but revenues still fall. If the revenue and cost curves are relatively flat, several designs are capable of producing more or less the same value-added, meaning that the company still has much leeway and that other factors must be considered to select a design.<sup>4</sup> One important factor to consider is the fact that the revenue curve is not only affected by the company's posture but also by the position of its competitors. A company wanting to penetrate a market that is already partially occupied by other companies has a revenue curve defined by residual demand and, to differentiate itself, it may be inclined to offer prices or response times that are different from its rivals. It might even find itself in a situation where all the most profitable positions are already taken.

The impact that the position of supply chain partners and competitors may have on a company's strategic posture<sup>5</sup> is illustrated in Fig. 2.16 for the forest products industry. Each actor covers a subset of the supply chain and it has its own total cost and response time curves. If a company's suppliers and customers have neither cost nor time advantages, or if they retain too high margins, they undermine the company's competitive position. Conversely, it is important to have an idea of competitors' costs and response times, even if they do not cover the same supply chain subset (competitors A and C in Fig. 2.16). This helps to identify the SCN segments that the company should improve. This could bring, for example, the company to subcontract activities that it does not do very well or, to the contrary, to develop new competencies that were not considered particularly important in the past.

<sup>4</sup>See Rosenfield et al. (1985) for a good discussion of the strategic implications of different forms of cost and revenue curves.

<sup>5</sup>Shank and Govindarajan (1993) show how to construct and use value chains covering the whole of an industry.



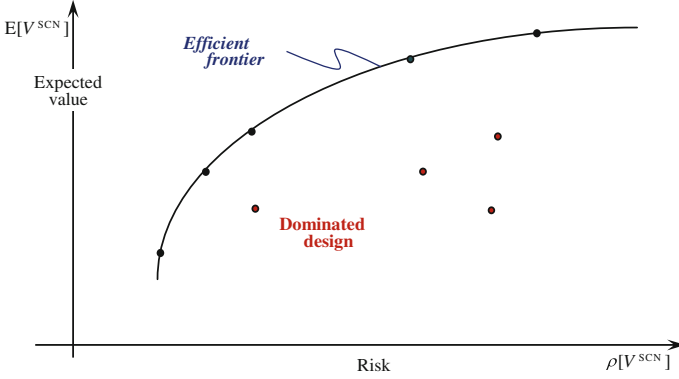


**Fig. 2.16** Partial value chains for the forest products industry

## 2.4 Risk and Social Responsibility

The preceding discussion ignores the impact of risk. Since we want to design robust supply chain networks that will perform well for several years irrespective of the plausible future that will occur, it is clear that we have a decision problem under uncertainty. This needs to be taken into account when evaluating potential SCN designs. The cash flows to consider are at best random variables, and it is not sufficient to use forecasted cash flows (or the average of random flows) in the evaluation process. The probability distribution of relevant cash flows and the decision-makers' attitude toward risk should also be considered. Most decision-makers are risk averse and ready to pay insurance to guard against uncertainty. When they do take risks, it is because they are hoping to increase the gains they get in return.

In finance, investment project evaluations often get around this problem by using expected cash flows (forecasts) to calculate a project's NPV, while increasing the opportunity cost of capital to account for risk. Thus, when estimating the WACC, a risk premium is added to the return  $r_S$  that shareholders want to receive. This premium is not easy to evaluate, and it is hard to generalize this approach to choose between projects with different risk levels. Another approach derived from portfolio theory (Markowitz 1959) is more suitable for our needs. It suggests evaluating a potential decision using a performance indicator based on a compromise between its expected value and its risk, the latter being measured by the volatility of the random outcomes associated with the decision. In an SCN design context, this



**Fig. 2.17** Value–risk efficient frontier

means that when demand, price, or any other problem parameters are random variables, the value of the network  $V^{\text{SCN}}$  defined by relationship (2.11) is also a random variable. Let  $E[V^{\text{SCN}}]$  be the expected value (average) of  $V^{\text{SCN}}$  and  $\rho[V^{\text{SCN}}]$  a measure of risk for  $V^{\text{SCN}}$ . When considering alternative SCN designs, their expected value and risk can be plotted on a Cartesian coordinate plane as shown in Fig. 2.17. By taking the upper envelope of these points, an *efficient frontier* similar to the one discussed previously (Fig. 2.13) is obtained.

To identify the points of this efficient frontier, it is necessary to find the designs that maximize expected value for several risk level  $\rho^o$  in an interval acceptable to the company. For a set  $N$  of potential designs and a given value of  $\rho^o$ , this is tantamount to solving the mathematical program

$$\max_{n \in N} E[V_n^{\text{SCN}}] \text{ subject to } \rho[V_n^{\text{SCN}}] \leq \rho^o, \quad (2.15)$$

Equivalently, the efficient frontier can be elaborated by maximizing a linear combination of value and risk

$$\max_{n \in N} E[V_n^{\text{SCN}}] - \lambda \rho[V_n^{\text{SCN}}], \quad \lambda \geq 0, \quad (2.16)$$

for different weights  $\lambda$ . However, in order to be able to solve program (2.15) or (2.16), a suitable risk measure  $\rho[V^{\text{SCN}}]$  must first be selected.

In his work, Markowitz used the *variance* as a risk measure but he was the first to recognize that this is not the best approach. Since the variance is defined by expression  $E[(V^{\text{SCN}} - E[V^{\text{SCN}}])^2]$ , it gives equal weighting to below and above average results, even though no one is against doing better than average. This explains the preference for downside risk measures, the most common of which are the *semivariance*  $E[(\min\{0, V^{\text{SCN}} - E[V^{\text{SCN}}]\})^2]$  and the *absolute semideviation*  $E[\max\{0, E[V^{\text{SCN}}] - V^{\text{SCN}}\}]$ . Two other popular risk measures are *worst-case-risk* and *value-at-risk*. The former corresponds to the lowest value of  $V^{\text{SCN}}$  and it often

leads to highly conservative decisions. The second is a quantile of the probability distribution of  $V^{\text{SCN}}$ . Regardless of the risk measure chosen, to use it in (2.15) or (2.16), one must be able to anticipate certain characteristics of the probability distribution of a design's value  $V^{\text{SCN}}$ . This generally requires the use of Monte Carlo simulation methods, a topic studied in detail in Chap. 10.

That being said, it should be clear that in order to design a robust and resilient SCN capable of creating value irrespective of the plausible future that eventually occurs, it is not sufficient to maximize expected value as suggested by (2.11). Instead, an efficient frontier first needs to be elaborated using program (2.15) or (2.16). Then, an efficient design can be selected based on the decision-makers' attitude to risk. The value–risk compromise found using this approach should provide an excellent SCN design for all business stakeholders. This design methodology may however be perceived as egotistical since it focuses on the interests of the company, without any explicit regard for its social responsibilities. Clearly, inasmuch as the order winners that customers value can include elements such as sustainability (see Table 1.1), the value creation objective causes the company to prefer all outcomes that customers consider important, which could include low environmental footprint, preserving natural resources, full employment, regional development, fair trade, ethical finance, and so on. Nonetheless, some companies wanting to act as leaders in this area may be willing to sacrifice some of their profits to contribute to the environmental, social, and economic development of the planet. According to a recent report of a corporate social responsibility (CSR) observatory in France (ORSE, [www.orse.org](http://www.orse.org)), 64 % of world-class companies' rank sustainable procurement as a priority in their CSR policy. This report also indicates that 51 % of these companies set quantitative sustainable procurement objectives.

For companies wanting to display CSR leadership, the aforementioned sustainable value creation objective may no longer suffice. The additional performance indicators to consider depend, in principle, on the company's *ecosystemic* posture, although it may be quite vague. It often takes the form of a statement emphasizing certain socio-environmental values. Within an SCN design context, a company's socio-environmental performance can be improved in three different ways. The first is to artificially inflate certain costs used in decision processes to induce sustainable behavior. This involves, for instance, subjectively increasing shipping costs because of the negative effects of transportation on the environment. Another example is increasing factory shutdown costs to account for the significant social impact of closing a production center. The second avenue involves imposing explicit or implicit socio-environmental constraints on decision-making. It is possible, for instance, to include a constraint on greenhouse gases emission in SCN design models, or even to eliminate any option that is not eco-efficient from the very outset. The advantage of adding an explicit environmental constraint in a design model is that it can then be used to elaborate an efficient (value, eco-efficiency) frontier by proceeding along the lines outlined above in relation to risk. A third option is to consider the reengineering of SCNs as a multi-criteria decision-making problem. This approach will be examined in Chap. 12.

## Review Questions

- 2.1. What is the conceptual relationship between *value drivers* and *performance indicators*?
- 2.2. What is a relevant cost? Suggest a few examples and explain them.
- 2.3. Explain the difference between fixed and variable costs using an example.
- 2.4. What causes economies of scale and scope?
- 2.5. How might diseconomies of scale be observed in a company?
- 2.6. What is ABC?
- 2.7. What is NPV?
- 2.8. The cost functions needed for operational decision-making and strategic decision-making are not the same. Can you explain why?
- 2.9. Estimate the annual inventory holding cost rate for your company or for a company of your choice.
- 2.10. Based on the preceding answer, estimate the annual inventory holding cost of all the products sold by the company you have chosen.
- 2.11. Why it is often difficult, in practice, to get the data needed to calculate supply chain costs?
- 2.12. Why is EVA important for the design of supply chain networks?
- 2.13. What is a value chain?
- 2.14. What impact does a (costs, response times) efficient frontier has on companies' supply chain strategy?
- 2.15. What impact does a (value, risk) efficient frontier has on companies' supply chain strategy?
- 2.16. How might efficient frontiers be elaborated in practice?
- 2.17. How could CSR be considered in an SCN reengineering project?

## Exercises

**Exercise 2.1** A company manufactures a product in batches. Every time the production of a batch is started, a setup cost of \$350 is incurred. The controller estimates the variable production cost at \$12 per unit. If the company produces a batch of 500 units, what is the total cost incurred? If 500-unit batches are always produced, what is the unit cost of this product?

**Exercise 2.2** Considering that the variable cost for the first unit produced of an item is \$10 and that economies of scale of 95 % apply (that is, economies of scale follow the power function  $10x^{0.95}$ ), what is the total cost incurred for the production of 1000 units? What is the marginal production cost for the 1000th unit manufactured? What is the marginal production cost for the 2000th unit?

**Exercise 2.3** Plans exist for a \$10 million investment project. The company requires a return of 15 % on its project, and its corporate tax rate is 20 %. If the project involves annual spending of \$250,000 for each of the first 5 years and revenues of \$4 million over the following 10 years, what is its NPV? Is it profitable to invest in this project? Explain your answer.

**Table 2.4** Transportation data

Origin	Destination	Distance	Weight	Cost
AL	UT	1530	852	\$676.57
AL	UT	1530	1682	\$1335.68
AL	UT	1530	1683	\$1124.08
AL	UT	1530	4345	\$2902.03
AL	UT	1530	4346	\$2522.85
AL	UT	1530	8203	\$4 761.84
AL	VA	613	783	\$381.32
AL	VA	613	1639	\$798.19
AL	VA	613	1640	\$654.52
AL	VA	613	3935	\$1570.46
AL	VA	613	3936	\$1236.30
AL	VA	613	8338	\$2618.97
AR	NH	1257	835	\$667.92
AR	NH	1257	1773	\$1418.22
AR	NH	1257	1774	\$1259.19
AR	NH	1257	3965	\$2814.36
AR	NH	1257	3968	\$2235.17
AR	NH	1257	7963	\$4485.56
AR	OR	1760	851	\$735.01
AR	OR	1760	1680	\$1451.02
AR	OR	1760	1681	\$1220.74
AR	OR	1760	4346	\$3156.07
AR	OR	1760	4347	\$2744.70
AR	OR	1760	8199	\$5176.85
CA	MA	2626	852	\$889.66
CA	MA	2626	1681	\$1755.30
CA	MA	2626	1682	\$1476.80
CA	MA	2626	4346	\$3815.79
CA	MA	2626	4347	\$3318.07
CA	MA	2626	8199	\$6258.30

**Exercise 2.4** You need to buy or lease a forklift for a distribution center. The lease that you are considering involves payments of \$2,000 at the beginning of each month for 36 months. The forklift can be returned at the end of 3 years without any extra cost. The purchasing price for the same forklift is \$65,000, tax included. You estimate that the resale value in 3 years will be about \$20,000. The company's average cost of capital is 10 %. If the two solutions are equivalent in terms of tax, insurance and maintenance,

- Which solution would you choose?
- Given that the only uncertain data is the forklift's resale value, what must it be for the two options to be equivalent?

**Exercise 2.5** In the road transportation industry, it is well known that less-than-truckload (LTL) shipping costs reflect economies of scale. Using an American LTL-rate benchmarking tool, the costs, distances, and weights associated with a sample of shipments on origin–destination lanes were obtained. The data collected is available in Table 2.4.

Your assignment is to:

- (a) Estimate a power function by regression (using Excel) giving the total cost of a shipment as a function of the weight of the load shipped and the distance between the origin and destination;
- (b) Show the existence of economies of scale using this function.

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