Processes, Systems, and Models

3

Learning Objectives for This Chapter

- Interrelations between business processes, quantitative models, and information systems
- Role of business process management in operations and supply chains
- Effects of management information systems in SCOM
- Management information technologies, e.g., ERP, APS, WMS, RFID
- Planning, problem, and decision
- Role of models and modelling in decision-making
- Quantitative methods of decision-making

3.1 Introductory Case-Study: AirSupply

Each time an aircraft is made, it is the result of assembling a multitude of parts representing a very large volume of orders. And what's true for the aircraft assembly line is true for the whole aerospace industry, where not only aircraft but also helicopters and satellites are built. Parts for manufacturing come from multiple suppliers from all over the world. Most of them are quite complex and need to fulfill the highest quality standards. Each time delay can result in very high costs. It is essential that all suppliers involved in the manufacture of an aircraft have real-time visibility of demand and inventory to adapt to fluctuations and changes of customer requirements. As a result, it is also essential for customers and suppliers to have a

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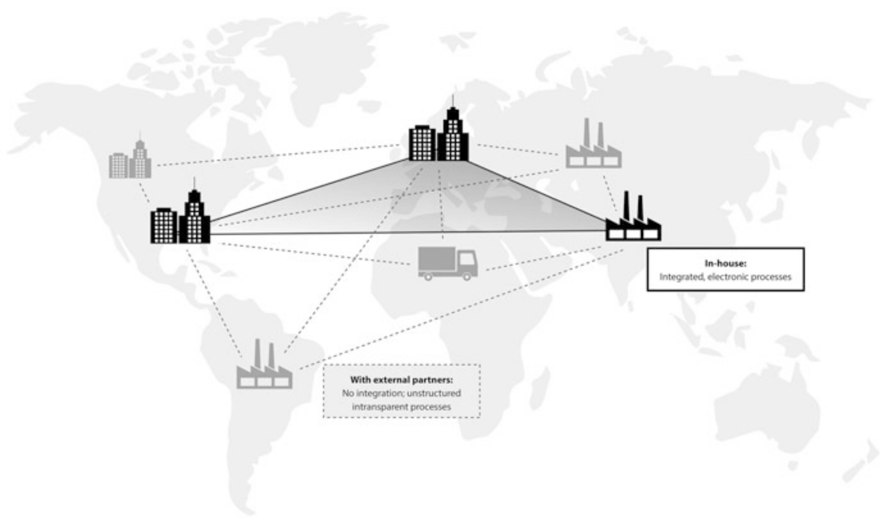

Fig. 3.1 Internal and external process integration in the supply chain

common tool that enables them to better collaborate and gain visibility over demand as well as inventory (see Fig. 3.1).

One such tool is SupplyOn's AirSupply solution which was developed in collaboration with Airbus/EADS and other major manufacturers and suppliers in the European aerospace industry. If AirSupply is mainly characterized by the networking of the whole Aerospace & Defense supply line, its main innovation lies in the fact that it provides all users with one single tool to view demand and inventory data. The solution combines major new technologies such as cloud computing, software as a service (SaaS), and e-procurement. It was developed in cooperation with SupplyOn which had many years of experience with web-based SCM solutions in the automotive industry.

AirSupply offers services for a number of SC processes, covering the entire product cycle. The following main functions are provided (see Fig. 3.2):

- Forecast collaboration;
- E-Procurement;
- Vender managed inventory (VMI).

3.1.1 E-procurement

AirSupply is a solution for an integrated SC where e-procurement plays a crucial role. Other than traditional procurement using enterprise resource planning (ERP) and simple EDI (electronic data interchange) communication, the e-procurement solution provides real-time visibility of demand fluctuations and closer networking between suppliers and customers who all have the same view on demand.

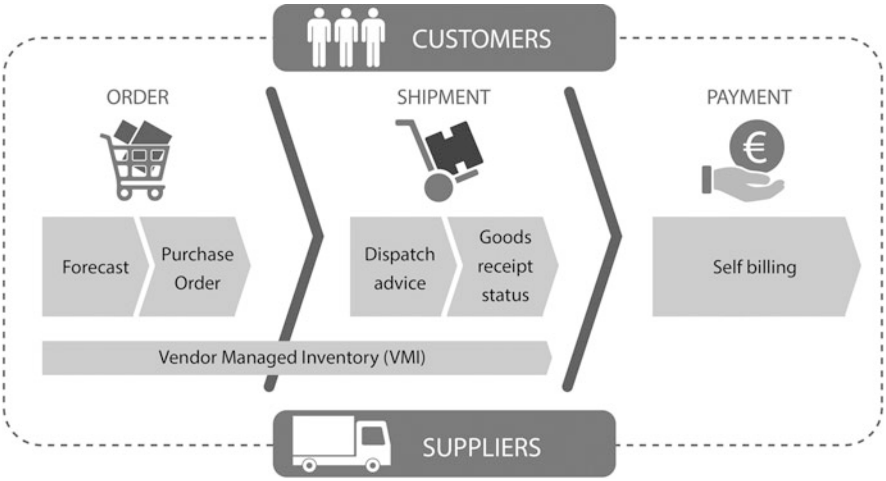

Fig. 3.2 Processes in supply chain management

Many of the other characteristics of the aerospace industry, such as complex parts and high-quality standards, make SC visibility and collaboration crucial factors for maintaining a competitive edge. Each airplane is produced according to individual customer requirements and several million parts are required at the right time to minimize inventories and prevent costly delays. Especially for suppliers using expensive parts from other suppliers, the financial risk can be high, but can be mitigated through e-procurement.

The following description of the purchase order process shows how AirSupply facilitates SC processes. After the customer creates the purchase order (PO) in their ERP, three different scenarios can be supported by AirSupply:

- The supplier accepts the PO without changes.
- The supplier accepts the PO with changes. The customer either accepts or makes a new proposal.
- The supplier accepts the PO without changes, but the customer requests a modification. The supplier can accept and dispatch the goods or the customer can make a new proposal.

AirSupply automatically synchronises the PO information from the cloud to the ERP system.

3.1.2 Vendor-Managed Inventory

The VMI process in particular shows a very strong need for integrated SC information systems (see Fig. 3.3).

In VMI, the supplier (or vendor) is responsible for managing the supply and usually agrees with the customer on a minimum and a maximum inventory level.

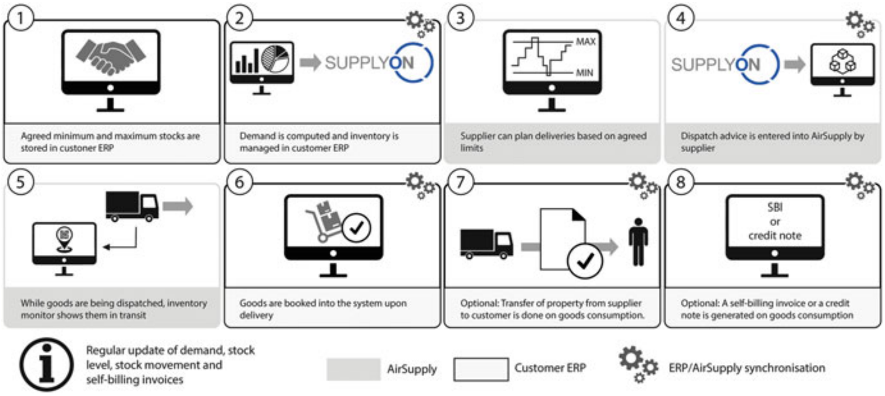

Fig. 3.3 Vendor-managed inventory process

This requires that the suppliers have timely and accurate information on the customer's inventory levels at all times. AirSupply strongly supports this SCM strategy by automatically advising suppliers when customers' inventory levels are critically low. Suppliers can also simulate deliveries to make adjustments prior to actually dispatching goods.

Closer collaboration has helped reduce safety stock and improve service level with the use of VMI. Manual work is also cut down as supplier data doesn't need to be entered and disputes linked to reception, inspection, and billing can be prevented.

3.1.3 Implementation

AirSupply is based on a Hybrid Cloud with SaaS (software as a service) solution that allows the management of established internal processes. More than 1000 suppliers were integrated into AirSupply by the end of 2012, and the solution connects all major firms of the European aerospace industry and has become the dominant platform. The common cloud platform enables standardized and integrated procurement processes while at the same time offering customized services to each individual company. Since cloud computing helps companies keep their hardware and software investments lower and more flexible, AirSupply offers a huge savings potential. Furthermore, cloud computing providers can guarantee a high level of data security and service reliability that a single company's IT, especially of a smaller company, could hardly do. At first glance, cloud services are particularly attractive for small and medium-sized enterprises (SMEs) that want to access massive computing power and specialized software with low fixed costs. For larger companies, the importance of having control over their IT infrastructure to secure and protect crucial internal processes could rather outweigh the benefits of cloud computing. However, the hybrid cloud solution can achieve the best combination of internal and external, fixed and variable IT systems for any company.

Discussion

1. What benefits of cloud computing can you identify for SC integration?
2. What benefits and drawbacks of e-procurement can you identify?
3. How does the AirSupply platform encourage its users to increase collaboration and develop mutual trust to share information along the SC?
4. What could prevent industry members from joining AirSupply?

3.2 Business Process Management

3.2.1 Process Optimization and Re-engineering

A process is a content and logic sequence of functions or steps that are needed to create an object in a specified state. A *business process* is a network of activities for accomplishing a business function. Processes have input and output parameters and may be tied to one functional area or be cross-functional. Today companies are organized on the basis of process. As said by W. Edwards Deming (Professor at Columbia University; 1900–1993), "if you can't describe what are you doing as a process, you don't know what are you doing."

Examples of processes include the following areas:

- Manufacturing and production, e.g., assembling the product;
- Sourcing, e.g., selecting suppliers;
- Human resources, e.g., hiring employees.

As an example, consider the process "Order fulfillment" (Fig. 3.4):

It can be observed that fulfilling a customer order involves a complex set of steps that requires the close coordination of the sales, accounting, and manufacturing functions. The basic concept for managing processes in an organization is called *business process management (BPM)*. BPM contains a variety of tools, methodologies to analyze, design, and optimize processes. BPM is comprised of the following steps (Hammer and Champy 1993):

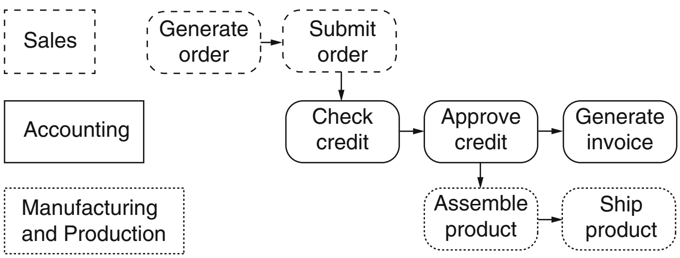

Fig. 3.4 Business process "Order fulfillment" [based on Laudon and Laudon (2013)]

- Identify processes for change;
- Analyze existing processes;
- Design the new process;
- Implement the new process;
- Continuous measurement.

Processes can be optimized subject to finding their best state with regard to

- costs,
- capacity,
- time,
- quality,
- service level,
- reliability,
- flexibility, and
- sustainability.

The process analysis results may be characterized by *effectiveness* (the achievement of process goals) and *efficiency* (performing the process with minimum costs). Processes that are both effective and efficient are called *optimal*. Optimal processes are characterized by effectiveness, efficiency, controllability, stability, flexibility, analyzability, observability, reliability, documentability, and continuous improvement capabilities.

Most of SCOM problems involve multiple objectives. The interrelation of objectives is called a "trade-off," which means that a manager has to find a compromise. For example, it is very difficult to achieve both low inventory and high customer service levels, or both high capacity utilization and short lead-time.

► **Practical Insights** *Sustainability* has become more and more important in process optimization in production, logistics, and services. Consider two apples in a German supermarket: an apple from South Africa and an apple from Germany. Which apple is more sustainable? Different costs such as transportation and warehousing costs should be considered in the analysis. In autumn, the German apple would be more sustainable. But in spring, the apple from South Africa is more sustainable, despite transportation emissions, because of the high warehousing costs and the corresponding energy consumption and emissions in Germany.

Process optimization in organizations is known as *business process re-engineering (BPR)*. BPR is an organization-wide philosophy of continuous process improvement. It is comprised of different views of process management such as operational, organizational, ethical, etc.

► **Practical Insights** Options for process improvement frequently lie in coordination. For example, in the automotive industry, the supply cycle between a customer order and car delivery is approximately 60 days. The car assembly itself accounts for only 2 of those days. This means that the value-adding processes comprise less than 5% of the total supply cycle. 95% are planning and coordination activities. Great potential for optimization can be found in these activities.

In SCs, the following options can be considered for *process improvement*:

- SC design and configuration (i.e., new market acquisition, lengthy time-to-market, non-resilient SC design);
- SC planning (weak flow capacities and lengthy supply cycle);
- SC operations (false priorities for customers' orders, imbalance of capacities and order volumes, too frequent disruptions and high costs for recovery);
- SC performance evaluation (performance of different departments such as logistics, transport, and production is evaluated locally for each department without any general links to the larger SCM perspectives); and
- SC execution (different levels of managers' qualifications, false or incomplete process documentation, weak consistency in process performance evaluation).

3.2.2 Business Process Modelling

In order to perform process optimization, as-is processes should be described. *Process models* describe SCOM activities from an information processing perspective. Process modelling can be referred to as descriptive modelling and serves as an interface for the development of information systems.

For *business process modelling*, a number of techniques and tools can be used. The most popular of these are as follows:

- SCOR (Supply Chain Operations Reference),
- ARIS (Architecture of Information Systems),
- UML (Unified Modelling Language) and
- IDEF (Integration Definition for Function Modelling).

These approaches can also be used to model the *workflow* of decision making processes. The process modelling serves to (1) describe processes and structures and (2) clearly illustrate those entities. For these purposes, different solutions have been developed, e.g., activity diagrams in UML and event-process chains (EPC) in ARIS.

The business process models typically have the following elements:

- Activities—Transform resources and information of one type into another type
- Decisions—A question that can be answered with Yes or No
- Roles—Sets of procedures
- Resources—People, or facilities, or computer programs assigned to roles
- Repository—Collection of business records

One of the well-known models for describing SC processes and measuring their performance is SCOR (Supply Chain Operations Reference Model) (see Fig. 3.5).

The SCOR model structure is not difficult to understand. Just imagine you are about to organize a party. What decisions are involved? First, we need to plan. Then we need to source food and drinks. The next step is to hold the party. Finally, your guests need to be delivered to their homes. The same principles are used in the SCOR model structure. It contains a description of planning, sourcing, making, delivering, and return processes in the SC at different levels of abstraction.

The main value of SCOR from the business process modelling point of view is that the standardized business process models are interlinked at three levels. In addition, a coherent system of performance indicators is correlated with the process models. Finally, the data origins used to calculate the performance indicators are explicitly provided. A *SCOR* project typically contains the following stages:

- Business process modelling
- Benchmarking analysis
- Business process re-engineering
- Process reference model.

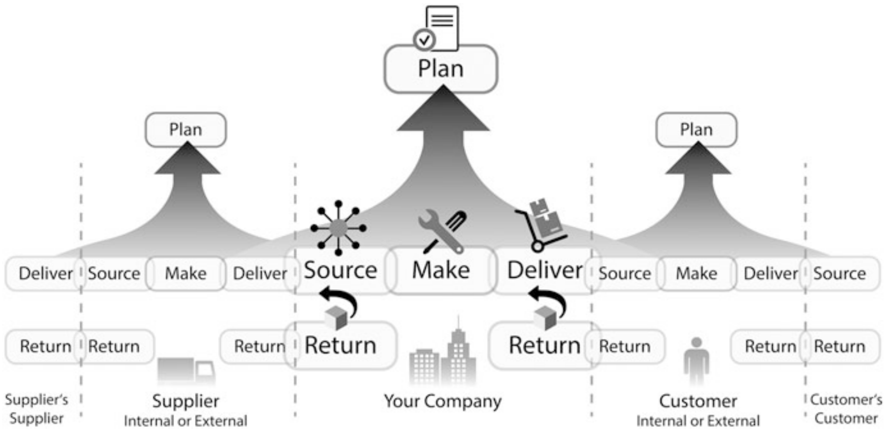

Fig. 3.5 SCOR model

3.3 Management Information Systems

3.3.1 Role of Information Technology in Supply Chain and Operations Management

SCOM managers say that where information is missing, material is also missing. A universal property of the management processes, irrespective of the problem domain, is that it has a notably *informational nature*, i.e. it is connected, first of all, with the collection, processing, analysis, and usage of data, information, and knowledge.

Management Information Systems (MIS) collect, process, store, and distribute information in order to support decision making, coordination, and control. MIS use data, i.e. they are streams of raw facts. Information is data shaped into meaningful form. For companies, MIS is an instrument for *creating value*. Investments in the right information technology (IT) can result in superior returns in terms of productivity, revenue, and long-term strategic positioning. On the one hand, MIS automate steps that were done manually before. On the other hand, MIS enable entirely new processes by changing the flow of information, replacing sequential steps with parallel steps, eliminating delays in decision making, and support new business models.

3.3.2 Types of Management Information Systems

The extensive development of IT for SCOM began in the 1980s. In the 1970s, first functions, such as accounting, were automated. In the 1980s, material requirements planning (MRP), sales and operations planning (S&OP), and MES (manufacturing execution systems) were developed. At the same time, additional functions, like product design and quality control, have been captured under the umbrella of CIM (computer integrated manufacturing).

Along with providing substantial advantages and help for managers, these systems were so called "island solutions," without integration with each other. Since these systems used the same data to a great extent, in the 1990s, integrated enterprise planning systems (ERP) were developed.

In the twenty-first century, SCM sparked the development of APS (advanced planning and scheduling) systems and different IT for SC collaboration. At present, mobile technologies, Internet of Things, smart manufacturing and Industry 4.0, Radio Frequency IDentification, e-business, and cloud computing belong to the trends of IT development for SCOM.

The variety of the existing IT can be distinguished according to the following groups.

Planning at the Enterprise Level

- ERP (Enterprise Resource Planning)
- MES (Manufacturing Execution Systems)
- WMS (Warehouse Management Systems)

Planning and Control for SC Coordination

- APS (Advanced Planning Systems)
- TMS (Transportation Management Systems)
- SCEM (SC Event Management)

Real-Time Control

- RFID (Radio Frequency Identification)
- T&T (Trace and Tracking)
- ASN (Automated Shipping Notification)

Business Intelligence

- Big Data Analytics
- Machine Learning
- Cloud computing

SC Communication and Data Interchange

- EDI (Electronic Data Interchange)
- E-Commerce
- XML (Extensible Markup Language)
- Mobile technologies, Android

We will consider some of these further in the next chapter.

3.3.3 Management Information Systems and Organization

IT provide a new level of coordination capabilities in SCs and have enabled a breakthrough in SC responsiveness and flexibility. Modern IT can potentially enable almost any integration and coordination concept. More important problems for efficient coordination lie in the organization sphere, collaboration culture, and trust.

First, the issues surrounding *investments in IT infrastructure* should be highlighted. Primarily, this concerns the amount a company should spend on IT. IT can be bought, but also rented or used via cloud computing. IT can also be available via outsourcing. Whatever option is chosen, the *total cost of ownership (TCO)* model should be used to analyze direct and indirect costs. Note that hardware and software costs account for only about 20% of TCO. Other costs include installation, training, support, maintenance, infrastructure, downtime, space, and energy. TCO can be reduced by the use of cloud services, greater centralization, and standardization.

Second, *IT project management* is a critical issue. As in any project management, activities in an IT project include planning work, assessing risk, estimating resources required, organizing the work, assigning tasks, controlling project execution, reporting progress, and analyzing results. Five major variables for planning an IT project are scope, time, cost, quality, and risk.

In spite of sophisticated project management, empirical data shows that 30–40% of IT projects exceed schedule and/or budget or fail to perform as specified. Frequently, the reasons are as follows: failure to capture essential business requirements; failure to provide organizational benefits; complicated, poorly organized user interface; and inaccurate or inconsistent data.

A road map in an IT project should be elaborated at all the management levels and include the following parts:

- Purpose of the plan
- Strategic business plan rationale
- Current systems/situation
- New developments
- Management strategy
- Implementation plan
- Budget

Third, the issue of *global organizations* has become a critical challenge for many IT infrastructures, especially in global SCs. Unfortunately, many companies fail to build the right IT for their global SCs. As an example, consider a typical scenario of disorganization on a global scale. A multinational consumer-goods company based in United States and operating in Europe would like to expand into Asia. World headquarters and strategic management are located in United States. The only centrally coordinated information system is financial controls and reporting. The company is divided into separate regional, national production and marketing centers. Foreign divisions have separate IT systems, e-business systems of different divisions and centers are incompatible. In addition, each production facility uses different ERP systems, different hardware, and so on.

Recommendations on the right way of organizing IT in global companies include the following actions. First, it can be advised to share only core systems which support functionality critical to the company: systems that share some key elements can be partially coordinated. It is not advisable to have exactly the same systems across national boundaries: local variation is desirable since IT must be adapted to local requirements.

3.3.4 ERP Systems

Enterprise resource planning (ERP) systems are comprised of integrated software modules and a common central database. ERP modules include but are not limited to:

- Production Management
- Inventory Management
- Sales
- Human resources
- Marketing
- SCM.

The modules are like a number of USB sticks which can be purchased all together or singulary. The working principle of ERP is based on the collection of data from different departments of a firm for use in nearly all of the firm's internal business activities. The advantage is that information entered in one process is immediately available for other processes. ERP uses

- master data (data not changed frequently, e.g., bill-of-materials) and
- process data (data changed operatively, e.g., current inventory level)

Advantages of ERP are as follows:

- Provides integration of the SC, production, finance, and marketing;
- Creates a commonality of databases;
- Can incorporate improved best processes;
- Increases communication and collaboration between business units and sites;
- Has an off-the-shelf software database;
- May provide a strategic advantage and increase company assets.

The *limitations* of ERP are as follows:

- Can be very expensive to purchase and even more so to customize;
- Implementation may require major changes in the company and its processes;
- Can be so complex that many companies cannot adjust to it;
- Involves an ongoing, possibly never completed, process for implementation;
- Expertise is limited with ongoing staffing problems.

► **Practical Insights** An integrated ERP system is costly. Its implementation will change organizational processes and structure. The project will take into account many years. At the same time, there are many companies with "self made" software for production planning, accounting, etc. The question is whether we should buy new ERP or develop and integrate self-made solutions? There is no absolute answer to this question. There are companies which develop their own solutions. In other cases, new ERP projects are successful. The key success factors depend much on the correspondence of the existing IT to the current and future needs of the company. It is also important how qualified and organized the IT department at the firm is.

3.3.5 APS Systems

At the beginning of the twenty-first century, SCM topics became more and more important. Some important modules such as "SC design" and "Distribution planning" were missing in ERP. In addition, ERP provided very limited support for mathematical optimization in scheduling. ERP also had other restrictions, such as planning against unlimited capacities. That is why a new generation of APS systems has been developed (Stadtler et al. 2015) (see Fig. 3.6).

An APS extracts data from ERP and uses it for optimization. Consider this example of scheduling in APS (see Fig. 3.7):

APS system:

- extracts some input data from different ERP modules,
- performs automatic calculations on the basis of scientific optimization methodology, and
- generates reports.

APS modules are mainly dedicated to deterministic planning. However, there are uncertainties on both the inbound (unreliable suppliers, machine breakdowns) and the outbound (unknown customer demand) sides. In order to hedge against

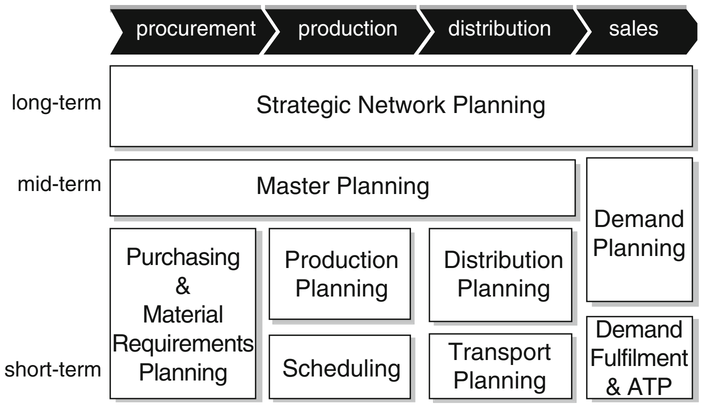

Fig. 3.6 Structure of APS system (Stadtler et al. 2015)

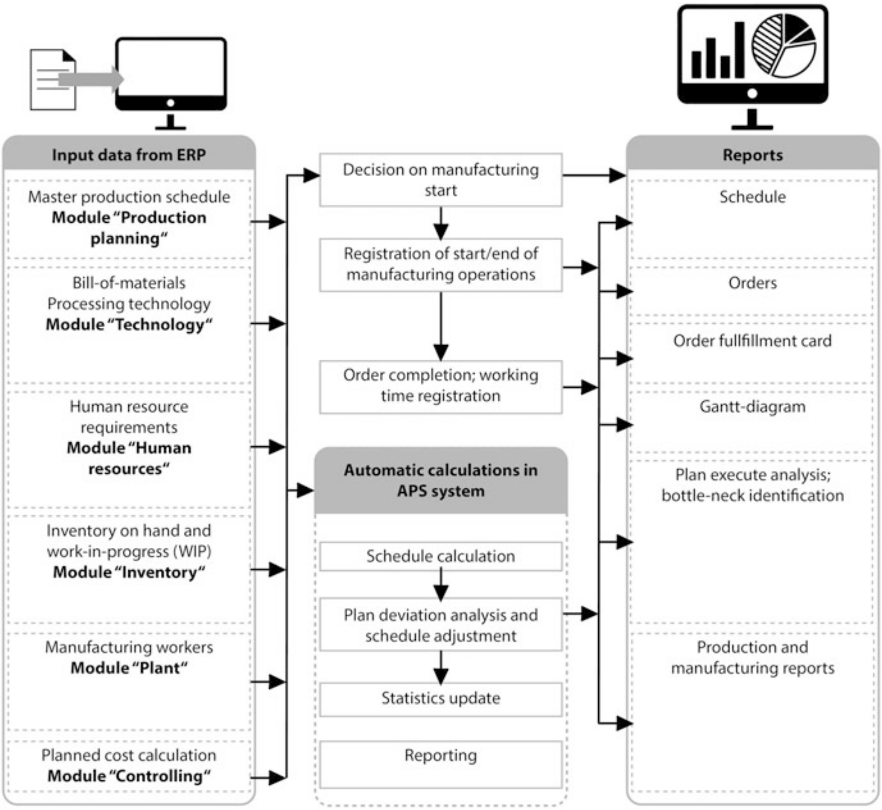

Fig. 3.7 Working principle of APS systems

uncertainty, buffers have to be installed—either in the form of safety stocks or safety times.

Practical application of APS is not easy. First, there is a discrepancy between the expectations of companies and the capabilities of the software. Second, optimization models can often not be solved within reasonable time limits, especially if interactive planning is desired. Third, the willingness to share information, e.g. about costs or capacities, is often rather limited. Problems also arise in using generic model formulations, which are often not sufficiently tailored to the needs of the specific application environment. APS appear to be most successful for intra-company SCs with centralized logistics control (Günther 2005).

3.3.6 SCEM and RFID

ERP and APS systems support activities planning. For *real-time control*, other systems are used. We consider two IT solutions for the *control* stage: SCEM and

RFID. Supply Chain Event Management (SCEM) aims at timely identification of deviations in SCs. The basis for disruption *alerts* and disruption recovery is a tolerance area of execution parameters' admissible deviations. SCEM is composed of five main functions:

- monitoring of processes;
- notification about an impermissible parameter deviation;
- simulating possible adjustment actions;
- selecting a control action to eliminate the deviation;
- measuring on the basis of performance indicators.

SCEM is based on three *main drivers*. First, tracking and tracing (T&T) systems, RFID, and mobile devices are used to provide current information about process execution. Second, the method of management by exception is used to filter information and to compare actual parameter values with planned ones. Third, the method of event-oriented planning is used to identify sensitive adjustment actions in the case of negative events.

One of the basic technologies for facilitating feedback in SC execution is RFID. In recent years, applications and research literature on RFID have grown exponentially. RFID is an automatic identification technology composed of RFID tags and specialized RFID readers. *Tags* are also called RFID transponders (abbreviation of transmitters-responders). Tags are attached to or incorporated into any kind of object (product, tool, animal, goods, human being, etc.) for the purpose of identification and tracking using radio waves. RFID *readers* read the information on tags and transfer it to a processing device. When applied to SCOM, RFID technology can provide several crucial advantages, but also has limitations (see Table 3.1).

The common target of RFID is to reduce costs created by manual operating, accelerate data receipt and transmission, and increase the preciseness and quality of data. RFID technology allows the *tracking of products throughout the SC* from supplier delivery to warehouses and points of sale. This contributes to the reduction of uncertainty concerning fluctuations in processes, improvement in the readability of the quantity and quality of items produced, improvements in safety (in particular, reduction of counterfeiting), and reduction of waste and theft. Some relevant figures are listed below:

- The reduction of error when picking a product in inventory is 5%.
- Thefts at retailers are reduced by 11–18%.
- Shrinkage at retailers decreases to 0.78% from 1.69%.

Table 3.1 Advantages and limitations of RFID for SCOM

Advantages	Limitations
Up-to-date data	Costs
Contact-free	Technical issues
"Bulk" reading	Privacy issues
Protection/security	Heat resistance

- Thefts from shelves decrease by 9–14 % while the reduction ranges between 40% and 59% in stores.
- Stock availability increases by 5–10%.

RFID is also believed to provide crucial benefits in ensuring SC stability/continuity by means of improved information sharing and SC monitoring support through a faster exception management. SCs can potentially become more flexible, responsive, agile, and secure by applying RFID.

Reduction of labor cost due to RFID is evaluated at 30%, 17%, or 7.5%, in distribution depending on the study for retail stores. Other estimations claim that saving in receipt of products in inventory facilities is 7.5% or 5–40%, depending on the study. Other figures state 9% in manufacturing, 90% or 100% in physical inventory counting, 0.9–3.4% in stores.

At the same time, the existing studies underline that RFID does neither explain nor solve the fluctuations of customer demand, transportation times, and inventory levels. It identifies and processes the data in the volume according to the tags, readers, and middleware functionalities, and at the places where they are installed. RFID also does not propose any control actions that should be taken to adapt a SC in the event of changes or disruptions at the execution stage.

3.3.7 Business Analytics and E-Business

During the last decade, new IT for SCOM has been developed. Details of managerial and technical implementation on these technologies differ, but most of them share attributes of intelligence. Since SCOM depends on the use of IT, in the coming years these new tools will change the landscape of managerial concepts and decision support systems for SCOM. Associating (and even embedding) IT and intelligence into SC planning and organizational structures has been discussed for over 10 years now. However, questions remain about the benefits and obstacles in allowing orders, deliveries and products to be able to plan and control their own progress through a SC. With new IT, data management becomes a competitive advantage for companies. Trends in IT development for SCOM include:

- Business Intelligence (BI) and Big Data Analytics,
- Cloud computing and SaaS (software as a service),
- E-Business, net marketplaces (e-hubs) and virtual enterprises,
- IoS—Internet of Services/Internet of Things and Industry 4.0.

BI comprises data and software tools for organizing and analyzing data. It is used to help managers and users make improved decisions. Presently, so called Big Data Analytics (cf. Chap. 16) are becoming more and more important. Data mining belongs to the group of business analytics that is comprised of tools and techniques for analyzing data.

With the help of *cloud computing*, hardware/software can be used as a service without buying IT. This allows companies to minimize IT investments. The drawbacks are concerns about security and reliability.

E-business consists of the use of digital technology and the internet to drive major business processes.

► **Practical Insights** In many e-commerce service SCs, especially in start-ups, the managers focus rather on the link between warehouses and customers and frequently undervalue the link between suppliers and warehouses. In manufacturing SCs the focus is rather on the link between suppliers and production, and the customer may play an underemphasized role in SCOM decisions. It is therefore important to consider integrating the SC from suppliers to customers for both service and manufacturing SCs.

E-commerce is a subset of e-business and consists of buying and selling goods and services through the Internet. Presently, M-Commerce solutions are being developed to include mobile IT into SCOM. In order to implement e-business, *Electronic data interchange (EDI)* technology is used. EDI ensures computer-to-computer exchange of standard transactions such as invoices, or purchase orders. Major industries have EDI standards that define structure and information fields of electronic documents. More companies are increasingly moving toward private networks that allow them to link to a wider variety of firms than EDI allows and share a wider range of information in a single system.

► **Practical Insights** Consider an example. Harley Davidson was facing problems with its suppliers, as the relationships were subpar and unsophisticated. Engineers focused on the suppliers' technical innovations and failed to consider whether they could produce the necessary volume, deliver on schedule, or meet cost targets. As a result, supplier components came in late and production was often put at risk. To resolve this problem, the company developed an internet-based SCM strategy where a web portal was created which enabled Harley Davidson and its suppliers to conduct transactions, from placing purchase orders to invoicing, on the internet. Nearly 300 of Harley's 695 parts suppliers logged into applications through the supplier portal. Suppliers can view production forecasts, account statuses, and are able to submit shipment notices and receive inventory-replenishment alerts. The web-portal has allowed Harley to achieve lower costs, consistent quality, and improved delivery performance.

Net marketplaces (e-hubs) are single markets for many buyers and sellers. They can be industry-owned or owned by an independent intermediary. E-hubs generate revenue from transaction fees and other services. The market principle uses prices established through negotiation, auction, or fixed prices.

In many industries, hierarchical SCs with predetermined suppliers' structures and long-term product programs evolve into *virtual enterprises and collaborative networks*. Their special feature is a customer-oriented networking of core competences and flexible, configurable SCs, conditioned by an enlargement of alternatives for searching for suitable partners with whom a cooperation enabled by Internet technologies is possible.

The main objective of a *virtual enterprise* is to allow a number of organizations to develop a common working environment or virtual breeding environment with the goal of maximizing flexibility and adaptability to environmental changes and developing a pool of competencies and resources. SCs in virtual enterprise are based on a customer-oriented networking of core competences through partner selection from a pool of available suppliers in a virtual environment according to customer requirements. Virtual enterprises focus on speed and flexibility. A virtual enterprise is enabled by building a united information space with extensive usage of web services.

Virtual enterprise structures are highly dynamic and their life cycles can be very short. Remarkable are alternatives for SC configuration. It is a great advantage to react quickly to customers' requirements. A virtual enterprise also builds a structural-functional reserve for the running of a SC. Unfortunately, virtual enterprises are mostly considered from the information perspective and don't deal properly with managerial and organizational factors. Our practical experiences show that there are only a few (if any) organizations that have managed to apply the primary idea of a virtual enterprise, but these often collaborate only a short time and then disperse, perhaps to form new networks with other enterprises. Two main obstacles cause this dispersal: trust and technical project documentation.

The development of the *Internet of Things* in a manufacturing context has been called *Industry 4.0* with reference to the three prior industrial revolutions: the steam machine, assembly line manufacturing, and computer integrated manufacturing (CIM). Even in our everyday life, WLAN-based communication between different devices such as refrigerators, kitchen stoves, and smartphones is possible. In Industry 4.0 manufacturing, both machines and materials are equipped with interconnected sensors in *cyber-physical systems*, take an active role in the process, and optimize it. The products and the machines communicate to each other. Materials will be able to communicate their purpose to the machines, making product lifecycles faster and more flexible. An important component of Industry 4.0 is *additive manufacturing* technology, especially 3D printing.

► **Practical Insights** Business Analytics and Industry 4.0 are expected to be path-breaking concepts for SCOM in the near future. All management activities are about data and information. By now, state-of-the-art IT allow storing and transmitting huge amounts of data. Managers must analyze all this data to extract what's necessary, and transfer it into information. In the future, managers will get the information they need at the right place, at the right time, and at the right quality. The preliminary actions for sorting and combining data will be done automatically by Business Analytics and Industry 4.0.

3.4 Problem Solving Methods and Research Methodologies

A baker bakes bread. A bus driver drives the bus. What do managers do? They make decisions. Decisions are made to solve problems. Decisions can be made regarding planning and control of operations and SCs. In this paragraph we learn the basic problem solving methods in SCOM.

3.4.1 Problems, Systems, and Decision-Making

For a *problem* to exist there must be an individual (or a group of individuals). This person is referred to as the problem owner(s) (decision maker) who:

- is dissatisfied with the current state of affairs within a real-life context, or has some unsatisfied present or future needs, i.e. who has some goals to be achieved or targets to be met;
- is capable of judging when these goals, objectives, or targets have been met to a satisfactory degree; and
- has control over some aspects of the problem situation that affect the extent to which the goals, objectives, or targets can be achieved (Daellenbach and McNickle 2005).

Rather than assume that we have a well-structured problem with clearly defined objectives and alternative courses of action, it is better to:

- represent the problem situation where issues are still vague or fuzzy;
- gain a comprehensive understanding of the various issues involved in decision making;
- formulate the problem correctly to ensure an appropriate level of detail and provide insights into the problem solution;
- perform decision making within the context of systems.

Most problems exist in the system context. A *system* is a set of interrelated components, which make up a united whole. Each component interacts with or is related to at least one other component and they all serve a common objective.

Environment is the aggregate of elements that do not belong to the system, but influence it.

One basic system characteristic is structure. *Structure* is the characteristic of steady links and interaction modes of a system's elements; structure determines the system's integrity, organization, and functioning; structure is the framework of a system. In practice, many SC structures are disrupted (e.g., Toyota' SC was badly affected by the tsunami in March 2011), and this concerns the SC's *structure dynamics* (Ivanov et al. 2010).

Dynamics is a system's change and evolution in object and process states in space and time as driven by the perturbation and control influences resulting from both planned transition from a current state to a desired one, or adaptation of a system to a changed execution environment.

Decision is the selection of an activity (or a set of activities) from several alternatives. Decisions are subject to constraints which limit decision choices and objectives which make some decisions preferable to others. Managerial decisions affect system goal-orientation through output performance. Decisions shape system behavior with regard to a certain goal (or multiple goals). Objectives and criteria play the most important role in making decisions.

► **Practical Insights** Each management decision has two components. The first one is an *analytical* component and the second one is a *behavioral* component. The analytical component is supported by *quantitative analysis* business analytics methods, while the behavioral component is based on the intuition and leadership qualities of the decision-maker as well as on external environment *behavior prediction and reaction* in regard to the decisions of suppliers, retailers, and customers.

Performance is a complex characteristic of the goal oriented results of the system's functioning. Managers must consider potential and real performance, and take into account the conformity of the achieved results with the goals set by management at the planning stage. Performance is measured with certain metrics or indicators (e.g., customer service level, on-time delivery, costs, etc.)

Basic problems in decision making are as follows:

- optimality,
- multiple objectives,
- risk and uncertainty, and
- complexity.

3.4.1.1 Optimal Decisions and Multiple Objectives

The optimal decision is the best one. Optimal decisions are very "fragile" and presume certain problem dimensionality, fullness, and the certainty of the model. In addition, optimal solutions are usually very sensitive to deviations. Moreover, decision making is tightly interconnected with dynamics and should be considered as an adaptive tuning process and not as a "one-way" optimization.

> **Practical Insights** Consider an example. Determining the optimal order quantity for some purchased items is a typical optimization problem. This optimization is based on the reduction of ordering and inventory holding costs, and, if so, the calculated order quantity is optimal only for the purchasing department. At the same time, this problem is tightly interconnected with transportation planning and customer service level improvement. So the real problem situation which exists is integrated inventory optimization.

The problems of applying optimization-based decision making are interrelated with complexity, uncertainty, and multiple objectives. A particular feature of optimal decisions is *multi-objective* decision making by managers with their own preferences that, in their turn, are always changing. Hence, it becomes impossible to build any general selection function for multi-criteria decision making. Finding optimal solutions is possible, but it can be very time-consuming. However, these optimal solutions can be used for benchmarking to estimate the quality of solutions obtained by heuristics or simulation models (see further in this chapter).

Multiple objectives conflict in the sense that they create a competition for common resources to achieve variously different performance objectives (financial, functional, environmental, etc.). A multi-criteria decision making (MCDM) strategy employs *trade-off* analysis techniques to identify compromise designs for which the competing criteria are mutually satisfied in a Pareto-optimal sense. One example of an up-to-date technique for MCDM is TOPSIS. For more detailed information on decision making theory, we refer to the studies on operations research, decision theory, and quantitative analysis in management, e.g., Taha (2009), Render et al. (2012), Dolgui and Proth (2010), Yalaoui et al. (2012).

3.4.1.2 Risk and Uncertainty

Uncertainty is one of the most critical issues in making decisions. *Uncertainty* is a system property characterizing the incompleteness of our knowledge about the system and the conditions of its development. Uncertainty is a polysemic term (poly—many, sema—a sign). Historically, the first terms related to uncertainty were accident, probability, and possibility, which we relate to Aristotle. Until the twentieth century, the mathematical basics and factor description of uncertainty were founded on probability-frequency interpretation and were related to Pascal, Ferma, Bernoulli, and Laplace. Modern probability theory is based on the research of Kolmogorov, who introduced an axiomatic definition of probability as a measure related to a system of axioms of a so-called probability space.

Uncertainty begets risk. *Risk management* is a methodological approach for managing uncertain outcomes. The concept of risk is subject to various definitions.

Knight (1921) classified "measurable" uncertainty as "risk." From the financial perspective of Markowitz (1952), risk is the variance of return. From the project management perspective, risk is a measure of the probability and consequence of not achieving a defined project goal. According to March and Shapira (1987), risk is a product of the probability of occurrence of a negative event and the resulting amount of damage.

Generally, in decision theory, risk is a measure of the set of possible (negative) outcomes from a single rational decision and their probabilistic values. A particular feature of risk management in SCs (unlike in technical systems) is that people do not strive for a *100% guarantee* of the result: they consciously tend to take risks. There is a problem of contradiction between *objective risk* (determined by experts, applying quantitative scientific means) and *perceived risk* (perception of managers).

There are three types of uncertainty which affect SCOM (Klibi et al. 2010; Dolgui et al. 2018):

- random uncertainty (i.e., problem in demand and supply coordination);
- hazard uncertainty (unusual events with high impact, i.e., ripple effect (Ivanov et al. 2014; Ivanov 2017a, b, 2018; Dolgui et al. 2018);
- deep uncertainty (severe disruptions) no information (game theory and utility functions).

According to the certainty of data, the following cases can be classified:

- no information (treated in game theory and utility functions);
- vague information (treated in fuzzy theory);
- random and stochastic information (treated in probability theory);
- determined information (treated in analytical models).

Uncertainty factors are usually divided into two groups:

- stochastic factors and
- non-stochastic factors.

The first group can be described via probability models. For the formal description of non-stochastic uncertainty, fuzzy description with known membership functions, subjective probabilities for the uncertainty factors, interval description, and a combined description of the uncertainty factors are used.

3.4.2 Models and Modeling

The concept of a model is widely applicable in natural human languages and is a general scientific term. It is characterized by polysemy, that is, widely expressed and reflecting different meanings depending on the applications and contexts. At present, there are several hundred definitions of the concept of a model and modelling. To sum up the different definitions, the following views of models and modelling are presented.

A *model* is:

- a system whose investigation is a tool for obtaining information about another system;
- a method of knowledge existence; and
- a multiple system map of the original object that, together with absolutely true content, contains conditionally true and false content, which reveals itself in the process of its creation and practical use.

Modelling is one of the stages of cognitive activity of a subject, which involves the development (choice) of a model, use of it to conduct investigations, obtainment and analysis of the results, production of recommendations, and estimation of the quality of the model itself as applied to the solved problem and taking into account specific conditions (Fig. 3.8).

Because of the *finiteness* of the designed (applied) model (a limited number of elements and relations that describe objects belonging to infinitely diverse reality) and the *limited* resources (temporal, financial, and material) supplied for modelling, the model always reflects the original object in a simplified and approximate way. However, experience shows that these specific features of a model are admissible and do not oppose the solution of problems that are faced by subjects.

3.4.3 Model-Based Decision Making

For each decision, managers use both quantitative and qualitative models. Quantitative analysis is a scientific approach to managerial decision making in which raw data is processed and manipulated to produce meaningful information. Consider the following example.

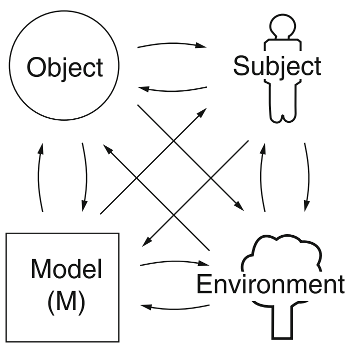

Fig. 3.8 Modelling stakeholders

Case Study "Redesigning the Material Flow in a Global Manufacturing Network"

Problem Description

Consider an enterprise that produces systems for energy transmission and has two locations: factory A is located in Europe and factory B is located in China. Both factories have deep manufacturing penetration; in other words, they are able to produce almost all the components and modules needed for the final product assembly. Both factories can assemble the same final products from the same components, known as shared components. The final assembly always takes place in the country where the customer builds its energy system. Whether the production of the shared components can be distributed within the network so that total network costs are minimized should be analyzed.

Model Development

Each manager applies both quantitative and qualitative methods for each decision. From the mathematical point of view, the problem can be represented as a number of origin points with some given capacities and destination points with some given demand. The production volumes should be delivered to the customers in such a way that total costs are minimized. This is a well known problem in operations research, namely the transportation problem. At the same time, the problem also comprises costs and risks which cannot be quantified within an optimization model, and therefore additional qualitative analysis is needed.

Input Data

At the first stage, four options for process design have been formulated:

1. Local manufacturing at A and B
2. Manufacturing at A for A and B
3. Manufacturing at B for A and B
4. Mixed manufacturing at A and B for A and B.

For the development of the mathematical model, the following data is needed:

- origin points
- destination points
- production capacity at the origin points A_i
- demand at the destination points B_j
- costs for production and transportation of a product unit from A_i to B_j.

Solution Development

The particular feature of the problem considered is that origin and destination points are actually identical. The model has then the standard format of the transportation problem and can be solved with the help of Excel Solver. Final decisions should be made based on analysis of both quantitative optimization results and managerial qualitative analysis.

Results Implementation

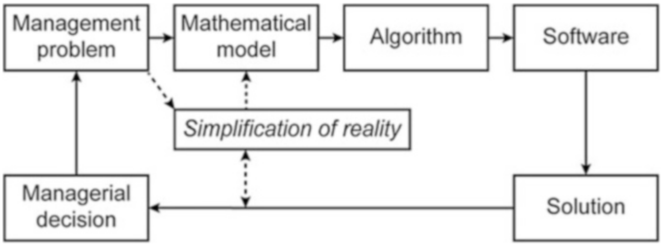

Fig. 3.9 Model-based decision-making process

From the point of view of cost efficiency, option 2 should be selected. However, there are some crucial risks. First, a single sourcing strategy is very risky since production and delivery shortages can occur. Second, if manufacturing in Germany should be relaunched, implementation costs would be very high.

The model-based decision making process is shown in Fig. 3.9.

We can observe that a *real management problem* is the initial point of the decision-making process. An example might be a facility location problem where we are given demand in some markets, possible locations and capacities of new facilities, fixed costs of having a facility in the SC, and transportation costs from each location to each market. We must decide where to locate the facilities and which quantities should be shipped from the facilities to the markets.

The next step is to transform the real problem into a *mathematical model*. For this transformation, we need to reduce the *complexity* of reality. This inevitably results in simplification. For example, we would assume deterministic capacity in our facility location model instead of considering fluctuations in demand.

We make this simplification in order to represent the management problem in such a way that the model can be solved with the help of existing *algorithms* within a reasonable time. In our example, we formulate the facility location problem as a mixed-integer linear programming model that can be solved with the help of simplex and branch&bound algorithms.

For implementation, *software* is needed. Small instances can be solved with the help of Excel Solver, but for real data, a professional solver such as CPLEX, Lindo, AMPL, Matlab, GAMS, Gurobi, and XPRESS exist. The software calculates the *solution*. In our example, the solution is suggestions on where to open facility locations and which product quantities should be shipped from each opened location to each of the markets so that total production and logistics costs are minimal.

The software calculates this solution. The most important question now is whether this solution is automatically our *decision*? NO! This is a solution to the mathematical problem. For the next stage, management expertise is needed to transfer this mathematical solution into managerial decisions. First of all, simplifications of reality should be reviewed. Second, so called *soft facts* such as risks, flexibility, etc. should be included in the analysis. That is why we prefer talking about *decision-supporting quantitative methods*.

3.4.4 Quantitative Models and Operations Research

Quantitative models for SCOM can be divided into three primary approaches. These are optimization, simulation, and heuristics. Hybrid models (e.g., optimization-based simulation models) also exist. *Optimization* is an analysis method that determines the best possible option of solving a particular operations or SC problem. Optimization has been a very visible and influential topic in the field of SCOM. The drawback of using optimization is difficulty in developing a model that is sufficiently detailed and accurate in representing the complexity and uncertainty of SCM, while keeping the model simple enough to be solved.

Simulation imitates the behavior of one system with another. By making changes to the simulated SC, one can gain an understanding of the dynamics of the physical SC. Simulation is an ideal tool for further analyzing the performance of a proposed design derived from an optimization model (Sterman 2000; Ivanov 2016, 2017a, b).

Heuristics are intelligent rules that often lead to good, but not necessarily the best, solutions. Heuristic approaches typically are easier to implement and require less data. However, the quality of the solution is usually unknown. An option for estimating the quality of heuristic algorithms may be the usage of optimization as a tool for "ideal" solutions to problems.

Operations Research (OR) is the application of advanced analytical methods to help make better decisions (INFORMS definition). OR deals with problems that may be described with mathematical models to find optimal or good solutions. An overview of OR-based methods is presented in Fig. 3.10. Basic OR methods and their application to SCOM include but are not limited to:

- Linear programing (production planning; revenue management)
- Integer programing/Combinatorial Optimization (scheduling, routing)
- Mixed integer linear programing (MILP) (SC design)
- Dynamic programing/Graph Theory (dynamic lot-sizing/SC contracting)
- Network theory (project management)
- Queuing theory (waiting lines: call centers, hotline services, process design, entertainment parks, services)
- Simulation (SC design, bullwhip-effect, etc.)
- Heuristics (genetic algorithms, ant colony optimization (ACO), application to scheduling and routing problems)
- Fuzzy/Robust/Stochastic optimization (data uncertainty).

The application of many of these methods to different SCOM problems will be considered in further chapters of this book.

3.4.5 Integrated Decision Making Support

Having read thus far in this textbook, you already have an overview of:

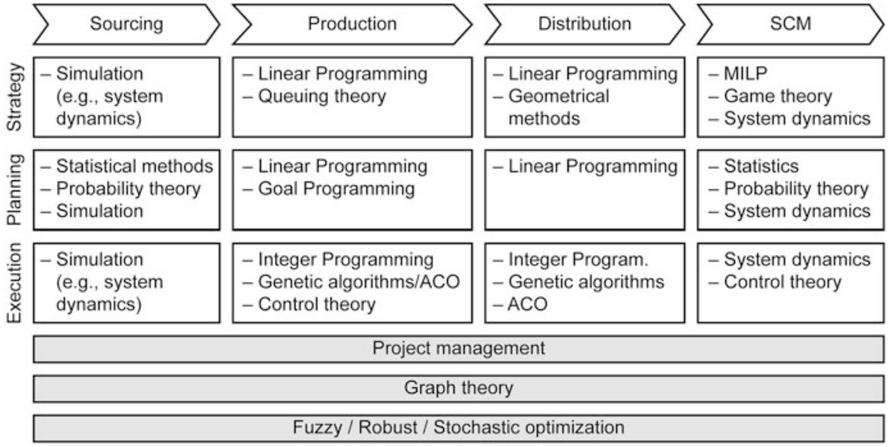

Fig. 3.10 OR methods for SCOM

- Decision-makers in SCOM
- Business processes in SCOM
- Methods of decisions making support in SCOM
- IT in SCOM.

Before starting to consider processes and decision-supporting methods in details, let us summarize our knowledge according to the triangle "*Process→Model→IT*". Process modelling and re-engineering are basic preliminaries for the successful application of quantitative models and IT. All three of these components are tightly interrelated with each other. The main blocks required for successful SCOM are presented in Fig. 3.11.

Many companies make a mistake by starting optimization directly with IT. However, before this, which data is necessary for which optimization models must be determined. Next, this data should be brought into correspondence with business processes and organizational structure.

In the block "Enterprise Supply Chain," typical functionality of ERP and APS systems can be used. In the block "Integrated SC," special EDI-driven software for SC coordination and collaboration are required. Finally, the block "Services and analytics" is responsible for reporting, data management, and KPI (key performance indicator) control. All of these models are based on business process models and mathematical models. Data management also comprises integration with some external IT like RFID, payment security systems, etc.

In Table 3.2, we summarize quantitative methods used in select modules of the SCOM information system.

In the next chapters of this book, we will learn many of these problems, models and methods in detail.

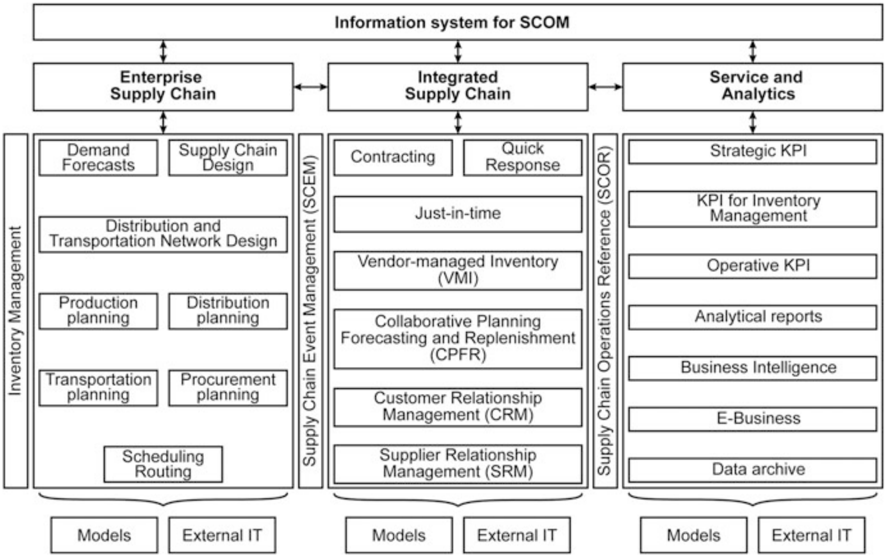

Fig. 3.11 Information system for SCOM

3.4.6 Research Methodologies

Quantitative methods, modeling and optimization are popular ways of conducting research in SCOM. Other research methodologies are qualitative-oriented and include case-study research, action research, surveys, and interview-based research (Kotzab et al. 2005; Yin 2014).

Case-study research is based on deductive analysis of existing practical examples described in literature. A single case, several isolated cases, or even embedded cases can be analyzed to develop general recommendations for a problem.

Action research presumes the active participation of the investigator in the problem solving. It can be, e.g., a traineeship in a company where students are involved in a project. Unlike in case-study research, the results of the project are typically unknown at the beginning. In an ongoing project, comparison of "as-is" and "to-be" states can be complicated. Benchmarking analysis can be successfully used here.

Surveys and interview-based research presumes data collection from different sources, e.g., interviews of experts in a particular area. The questionnaires are designed and evaluated with the help of statistical methods. Frequently, the structural equation method is used.

Table 3.2 Data, decisions, and methods in SCOM [based on Ivanov (2010)]

Input data	Performance indicators	Examples of solution methods	Result (output)
Demand forecasting			
Statistical sales data	Forecast error minimization	Exponential smoothing; Regression analysis	Demand forecast
Supply chain design			
Location data Demand forecasts; Capacity data; Transportation (time, costs, etc.)	Cost minimization	Center-of-Gravity Warehouse Location Problem (WLP) CPLM (Capacitated Plant Location Model) Location-Allocation Model	How many production and distribution centers are needed, where, and of what capacity?
Distribution-transportation network design			
Customers and Suppliers Supply Chain Design Demand forecasts; Transportation (time, costs, etc.)	Cost minimization; Service level maximization	Transportation problem and its multi-stage modifications	Which products and of what quantity should be shipped to which destinations?
Inventory management			
Demand; Lead-time Holding, ordering, and warehousing costs Service level; Capacity data	Cost minimization; Service level maximization	Cycle inventory optimization (EOQ/EPQ); Safety inventory optimization; Multi-echelon inventory management; ATP/CTP	When and how much to order? What is optimal service level? Where to place inventory in the SC?
Sales and operations planning			
Demand Costs Inventory Capacity	Cost minimization Revenue maximization	Mathematical programming	Aggregate plan for 1–18 months
Distribution and transportation planning			
Sales and Operations plan Costs Inventory Transportation Capacity	Cost minimization	Mathematical programming, Heuristics	Aggregate plan for 1–18 months

(continued)

Table 3.2 (continued)

Input data	Performance indicators	Examples of solution methods	Result (output)
Scheduling and routing			
Master production schedule; Machine capacity; Due dates; Costs	Minimize completion time Maximize utilization of facilities Minimize work-in-process (WIP) inventory Minimize flow time	Combinatorial optimization, Heuristics	Schedules and delivery routes

3.5 Integration of Business Analytics, Simulation, and Optimization

Success in SC competition is highly dependent on analytics algorithms in combination with optimization and simulation modelling. Initially intended for process automation, business analytics techniques now disrupt markets and business models and have a significant impact on SCM development.

> **Practical Examples** Electronic retailers use their extensive customer transactional and behavioral data to offer new ways of trying, experiencing, and purchasing their products (e.g., Amazon with Alexa). PwC works with a large car company looking to introduce autonomous vehicles for the public (Wilkinson 2018). Part of this work employs deep reinforcement learning to develop rules. Together with simulation, deep reinforcement learning is used to determine "optimal" decision rules that allow the vehicles to maximize efficiency while also satisfying customer trip demand. The software environment for the project uses the extensible and practical environment of AnyLogic multi-method simulation software to lever the capabilities of DL4J for the deep learning environment. Autonomous cars are becoming more common and the features are already in many consumer cars. Artificial intelligence (AI) becomes more pervasive in the real world with every project, and necessarily it must be part of simulation. This means AI will not only be part of simulations, but simulation will also help to develop the AI.

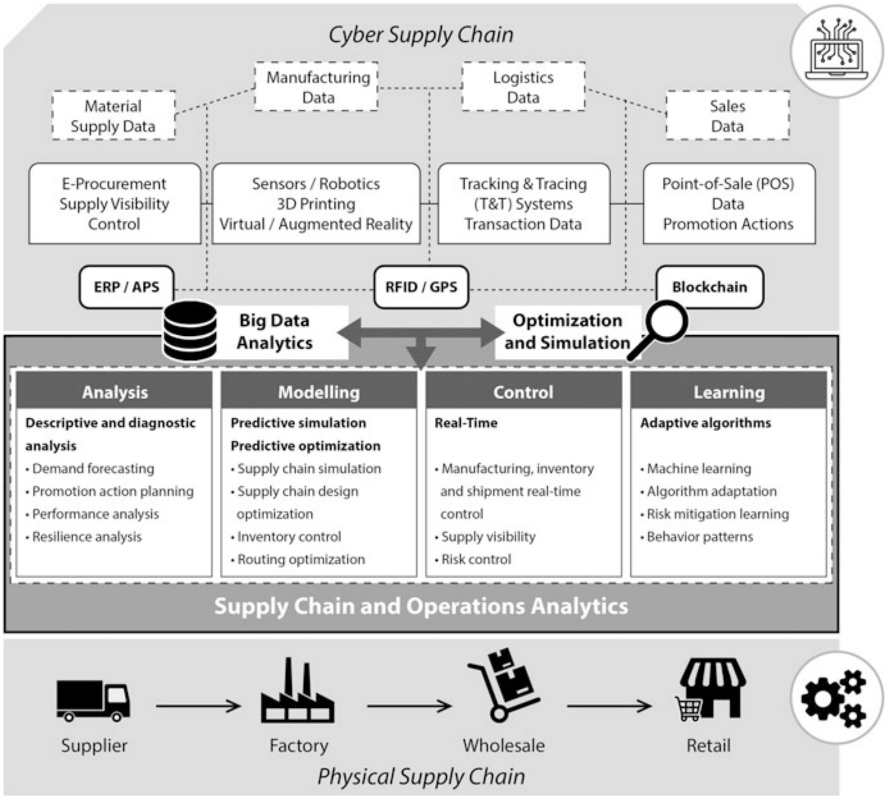

Fig. 3.12 Supply chain and operations analytics

In the past decades, simulation and optimization have played significant roles in solving complex problems in SCOM. Successful examples include production planning and scheduling, supply chain design, and routing optimization, to name a few. However, many problems remain challenging because of their complexity and large scales, and/or uncertainty and stochastic nature. On the other hand, the rapid rise of business analytics provides exciting opportunities for Operations Research and the reexamination of these hard optimization problems, as well as newly emerging problems in SCOM (Fig. 3.12).

Examples of SC and operations analytics applications include logistics and SC control with real-time data, inventory control and management using sensing data, dynamic resource allocation in Industry 4.0 customized assembly systems, improving forecasting models using Big Data, machine learning techniques for process control, SC visibility and risk control, optimizing systems based on predictive information (e.g., predictive maintenance), combining optimization and machine learning algorithms, and simulation-based modeling and optimization for stochastic systems (Ivanov et al. 2018).

The application areas of Supply Chain and Operations Analytics can be classified into four areas, i.e.,:

- Descriptive and diagnostic analysis,
- Predictive simulation and prescriptive optimization,
- Real time control, and
- Adaptive learning.

Sourcing, manufacturing, logistics, and sales data are distributed among very different systems, such as ERP, RFID, sensors, and blockchain. Big Data Analytics integrates this data to information used by artificial intelligence algorithms in the cyber SC and managers in the physical SC (cf. Fig. 3.12; see also Chap. 16). As such, a new generation of simulation and optimization models have arisen. The pervasive adoption of analytics and its integration with Operations Research shows that simulation and optimization are key, not only in the modeling of physical SC systems, but also in the modeling of cyber SC systems and for learning them.

3.6 Key Points

Organizations are structured by processes. Any organization or business strategy is influenced by technology. A business process is a network of activities for accomplishing a business function. The basic concept of managing processes in an organization is called business process management and includes a variety of tools, methodologies to analyze, design, and optimize processes. The analysis of process results may be characterized by effectiveness (the achievement of process goals) and efficiency (performing the process with minimum costs). Process models describe SCOM activities from an information processing perspective.

At the enterprise level, such MIS as ERP, WMS, and TPS systems are used. At the SC level, APS and SCEM systems can be applied. During the last decade, new IT for operations and SC integration have been developed. Examples include data mining, cloud computing, physical internet, pattern recognition, knowledge discovery, and early warning systems, to name a few. Trends in IT development for SCOM include Business Intelligence and data mining, cloud computing and SaaS, E-Business, and Industry 4.0.

For each decision, managers use both quantitative and qualitative models. Quantitative methods are based on Operations Research techniques. Qualitative research methodologies include case-study, action, and survey research.

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