

Simulation of Distribution Systems

Agostino G. Bruzzone
MISS - DIPEM University of Genoa
Via Opera Pia 15 - 16145 Genoa, Italy
agostino@itim.unige.it

Bernd Noche
University Duisburg-Essen - Faculty of Engineering Sciences
Lotharstr. 1 - 21 - 47057 Duisburg, Germany
b.noch@uni-duisburg.de

Simone Simeoni
Liophant Simulation
Via Opera Pia 15, 16145 Genoa, Italy
simone.simeoni@liophant.org

1. Introduction

The structure of a distribution system does not only consist of an arrangement of stores, sorters, order picking areas, packaging and dispatch areas and their connection by conveyors. It also consists of control systems to complete orders and deliver goods to a truck by a scheduled time. This means that the focus is not only on pure material flows, but also on operating rules, which ensure that customers receive the goods they ordered within specific deadlines.

Naturally, those rules concerning operative workflows also have to consider the installed capacities. They must also consider that service degrees have to be met and that restrictions, such as the size of storage areas, and additional conditions, like shift models, are predetermined.

Distribution systems are being developed in an uncertain future that is rapidly evolving due to the nature of demand, under the direct influence of end customers, but also because of strong competition in the Retail sector whose efforts are constantly aimed at renovating and reorganising processes to improve operations and introduce new services. In effect, many parameters may change: customer requirements with respect to delivery frequency and variety of articles, quantity streams, distribution of articles, competition, company mergers, assortment shifts, product cycles, purchasing patterns, etc. The

objective should be to cover different development scenarios with the installed techniques.

A logistic system operator should be the most interested in using simulation models: for him it's important that all crafts work and cooperate in a rational manner, that personnel assignments and shift arrangements are combined efficiently with the material flow system, that maintenance concepts achieve the intended availability, and that promises to customers can be kept even under unusual conditions. Contract in, contract out, after acceptance it's all water under the bridge, but the operator, after purchasing the system, has to work with it for many years. Simulation techniques are based on data which are needed for planning anyway; so they don't permit any "planning gaps" or "black wholes" and lead to coherent solution concepts. It delivers operating figures, instead of approximations, faith, goodwill and forecasts; thus, the simulation provides hard evidence about the economic efficiency of the concepts.

In this paper, the authors present some important aspects about simulating distribution centres, illustrating the current state of the art. They also put the spotlight on the main purpose of a simulation study, while showing the shortcomings and the need for further research and development.

2. Questionnaires

Whether the application of a simulation is meaningful and to what extent depends first on whether the risks and the potential which may be economically affected are large enough or not. Thus, one will find only limited rationalization potential, for example, in an order picking system, such as a high-bay racking system where one or two workers drive a fork-lift through the aisles in one shift. But a distributing conveyor serving dispatch lanes may be requested to carry out sorter tasks so that timely provision of truck loads runs out of orders.

And plans may focus on a distribution system in which all components – from stock via sorters and conveyor techniques – easily cover the expected maximum throughputs. However, no one knows how all the components interact, and if situations may arise which make the whole system questionable. Practically all distribution system suppliers can demonstrate functioning systems and present reference lists of satisfied customers. Unfortunately, nearly all distributors also have lists of customers who should not be mentioned. On which list a distribution system operator appears does not only depend on the reputable actions of the suppliers but also in a special way on the accurateness which

with the operator has dealt with his solutions. And simulation techniques can be used to develop accurate planning in which all significant aspects are taken into consideration.

By summarising the experiences from several studies, we can state, with the aid of the simulation technique, the following most frequently asked questions:

- Does the distribution system provide the requested order mix in the predetermined time slots?
- Where are bottlenecks, weak points and rationalization potential?
- How large are the order throughputs and how do they spread?
- How extensive is the utilization of critical systems and components over a period of several hours?
- What influence does the organization, e.g. shift models, processing of special order types etc. have on the whole system?
- How does personnel assignment, qualification and organization affect the system?
- How does the distribution system act at the beginning of a shift and how does it behave at the end?
- What effect does the breakdown of components have on system output?
- How fast can a line get rid of a tilt (e.g. after a breakdown or because of extreme requirements)?
- What about provisions for empty boxes (or pallets)?
- What influence do special orders (e.g. waste disposal, stacks of empty pallets, operating supply items and auxiliaries, spare parts) have on the operation?
- How can the supply of goods be ensured in several storage areas and order picking areas?
- What efficiency can be expected from distribution centres when two alternative development scenarios occur?
- How do Retail product mix trends affect the efficiency of the Distribution Centre?
- How can the return of empty containers/boxes/pallets be managed, and how can such services be reorganised considering the new supports (i.e. fresh vegetable foldable plastic box, or new intelligent tag systems)?
- How well do Distribution Centre Processes match supplier deliveries?
- How well do Distribution Centre Processes match transportation to final stores and actual demand?
- What is the best policy for strategic *hoarding* based on market expectation and Distribution Centre capabilities and facilities?
- What are the Best Policies for serving stores based on priority, demand and available goods?

- What are the Best Policies for Grouping Orders based on Logistics special fares and based on Final Store Expectations?

Those rather general and higher-level questions will be joined by concrete detailed questions in the single projects like in order picking by a goods-to-man-principle:

- Which order picker gets what order?
- What guarantees can be provided to ensure that all places are configured in the same way?
- How can longer waiting times be avoided?
- How many buffer places are needed in front of and behind the stations?
- When will the order be assigned to the order picker?
- What are the effects of gripping time fluctuation?
- Are article pallets able to approach several places successively?
- How can the sequence of stock removal orders be respected?
- What are the best mastering and packaging solutions from a logistics viewpoint?

Such questions show very clearly that the simulation technique considers many points concerning system dynamics, especially in reference to the highly stochastic nature of the components involved. Where cooperation between components is important, where accidental influences and individual control strategies apply, and where material flows merge, human imagination is usually overstrained. On the other hand, the questions are also the decisive points that pinpoint modelling accuracy and that define the efforts linked to data collection.

3. The database

Various types of data are needed to simulate a distribution system. The question is whether all data must really be provided or whether they can be generated by certain rules. What data should normally be collected is discussed in the following section. The diffusion of ERP systems in this sector confirmed, as in other application areas, that such infrastructures are useful for defining clear procedures, even though they don't solve the overall management problem. Usually, these systems help to provide good data references to feed the simulation; therefore, it is of critical importance to integrate such transactional information with process details and events in order to develop a correct/complete simulation model.

The usual starting point is a distribution system layout which contains all relevant technical installations, e.g. store, conveyor technique, machines, buffers, etc. The layout is needed

in particular to determine distances and capacities and to explain the arrangement of components and interfaces. A central point is also the article base for products that run through the system. Depending on the branches, different data are needed. Often such data include the following information: article number, dimensions, weight, piece per pallet or box, minimum durability and batch number. Information about customer orders is also very important. This also includes data such as customer number, article, quantity, time of generation, time of delivery and tour. These data describe the customer demand and all orderlines a customer has ordered and which have to be available to dispatch at a given time. The sequence of customer orders guided through the system is scheduled by the route table. The route table contains information about tour, tour start time and even data about tour capacity (number of pallet storing positions or number of trucks). When modelling storage systems, it's often useful to define a store initialisation level in order to shorten the duration of a simulation and to set a realistic filling level of the storage areas at the beginning. The initialisation simply contains information about article and quantity, while an allocation strategy is implemented to distribute goods in the store. The Goods arrivals describe incoming goods during the day that will be immediately placed in storage, repacked or treated in another way. Data often consists of truck number, time of arrival, article, and quantity. Goods arrival data can also be received through a direct link with production or from other storage areas. The data then consider the appropriate logistic aspects involved such as number of pallets per hour, batch size, etc.

Data files of conveyor techniques contain information about speed of conveyor belts (lifters, turntables, distributing conveyors), control strategies at junctions, operation control rules, switching times, etc. Work places and machines require data that characterize time of operation and set-up. In addition, they also consider gripping times of the order pickers, packing times at the packing tables as well as dwell times at scales, wrapping stations or palletising.

All this data are summarized as organisational instructions which, for example, comprise shift models, personnel assignment and other instructions describing operational processes.

Control strategies involving processing time of customer orders as well as all other orders (storage arrival and retrieval orders, palletising orders, order assignment to stackers), are filed in system specifications or flow charts. They control each system component (store, order picking, sorting, palletising, dispatch) but also super-ordinate sequences to coordinate the various material flows.

Investigations about system availability or breakdowns are carried out in many simulation studies. Essential data required for modelling are summarised in fig. 1.

In addition current Retail business situations involve a significant amount of challenges where simulation can make a significant contribution. In fact, owing to the growth of this sector (due to the large increase in the retailers market share in Europe and to merging and acquisition procedures), networks have to be redesigned. Currently, several projects are underway to redefine regional logistics, and to create/renovate distribution centres and tasks/policies. Therefore, it becomes necessary to address very different products, creating ad hoc logistics platforms that not only distribute, but often have to carry out operating procedures on products. Some very good examples involve the fresh goods supply chain, where the new regulations (i.e. UNI 10939 11020, ISO9000:2000, HACCP, CE 178/2002) require that current operations undergo a drastic review.

New market channels are appearing in the retail sector: B2C E-commerce for distributing general goods to end customers is growing and some experiences have demonstrated that it could be managed quite effectively, at least in some scenarios. Even when the expectations are not very positive, these new activities, owing to retail market penetration strategies, require a very detailed design of the supply chain as well as distribution centres that will guarantee the best results while limiting costs.

From this point of view two important factors related to the logistics network problem in Distribution Chains are Customer Satisfaction and Customer Behaviour. Interesting results have emerged in this sector regarding demand estimates and customer behaviour. The simulation is an important support tool for validating and running these models since it can be used to quantitatively and statistically measure the impact of hypotheses and estimates. In this sector it is very important to understand that there are no crystal balls, while forecasting can be very useful in combination with M&S for risk analysis and statistical estimates about opportunities. Simulation is very useful in this context to provide estimates of customer satisfaction by measuring quantitative indicators in the virtual environment based on logistics decisions.

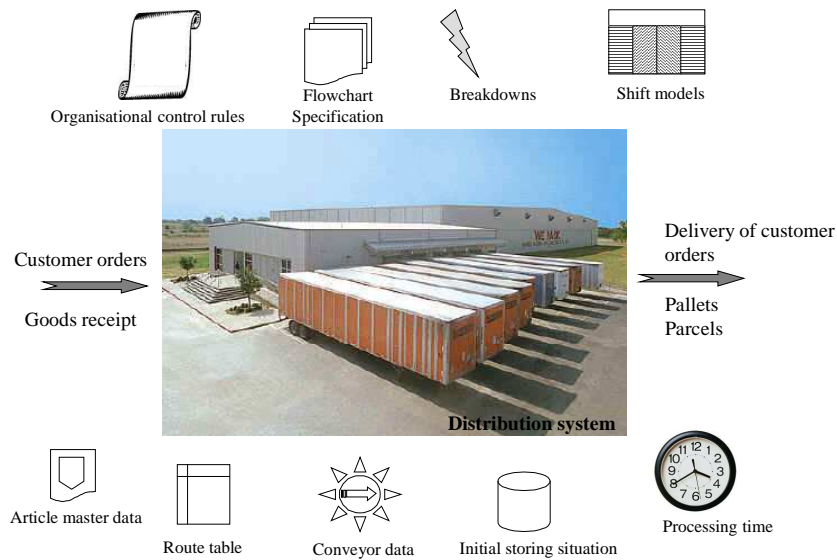


Fig. 1: Elements of a database for a distribution system simulation

4. Aspects of a simulation model

Plans call for the construction of a new distribution system involving deliveries of boxes with packed meat products.

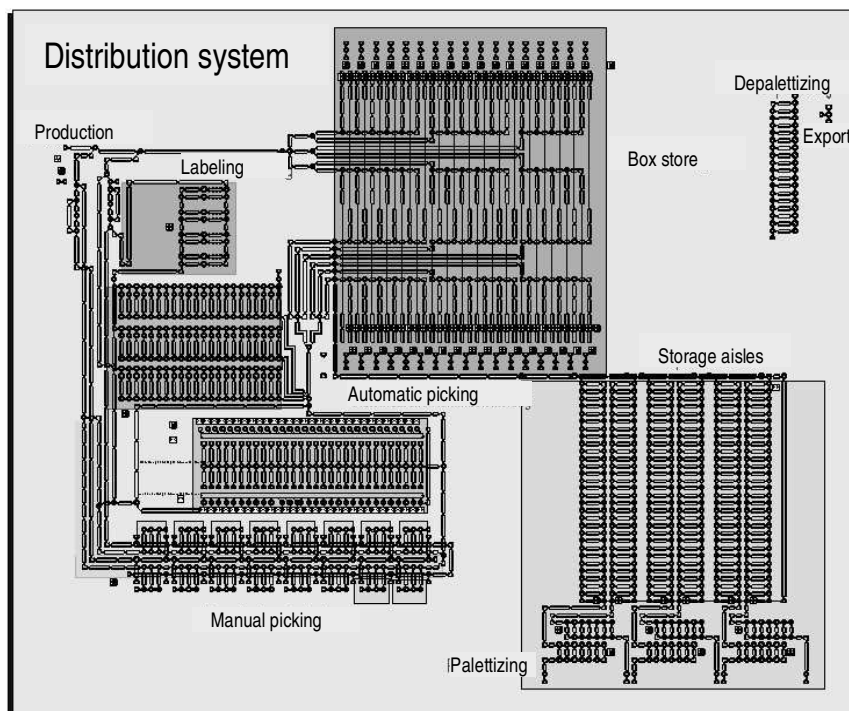


Fig. 2: Layout oriented simulation model of a distribution centre

The distribution system has multiple tasks and functions:

- Conveyor technique to connect production and storage systems
- Storage systems as a buffer for finished products and order picked boxes as well as remainder boxes
- Order picking areas consisting of automatic and manual picking
- Customer labelling and marking of products in accordance with specifications
- Order picking and labelling of articles for exportation
- Box palletising processes consisting of buffers, sorter systems and palletising machines
- Truck loading dispatch area
- Stock removal area to deliver external products and empty pallets as well as empty boxes.

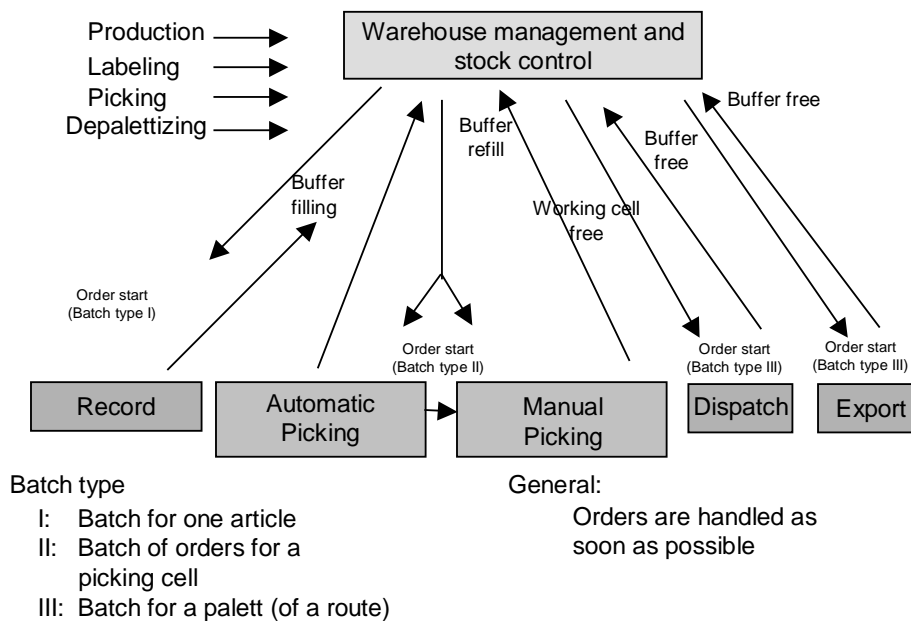


Fig. 3: Interaction of order picking and dispatching operations

The processing principle concerning the interaction of warehouse management and control of the functional areas is represented in fig. 3. For a tour (route) of a specific time the order picking starts picking customer boxes. Order allocation in picking to the individual picking cells depends on the status of the corresponding cells.

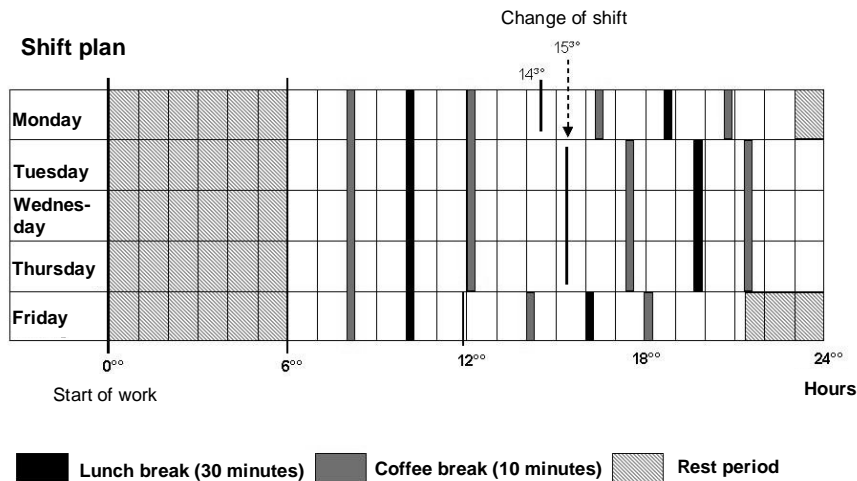


Fig. 4: Shift model

A more detailed view of the shift model is represented in fig. 4. During the week the shift model varies depending upon working day and order load. The ending of the first shift is marked in the plan as a line.

Simulation results

The model is a system with very large throughputs. In the simulation models this leads to the fact that many events have to be administrated at the same time and a lot of boxes must be modelled for animation. Therefore, only a simulation software can be used in this case since it can perform very fast simulation runs.

In conclusion, it can be stated that the planned system with the specified control strategies will not meet performance requirements. The application of the simulation technique explains the problems.

Some examples:

- The heart of the distribution system - the order picking system – fails to achieve the intended throughput because of several reasons. The planned sorter conveyor is often very full. Thus the picking places cannot be supplied continuously with article boxes since the supply to the sorter has to be locked phase by phase. Otherwise, system deadlocks occur which block the entire system. The sorter conveyor may not be used as a buffer for the remaining boxes. Remainders must be sent back to the store as soon as possible. In order to minimize the flow of remainder boxes it was decided that each article box has to be dedicated as soon as it leaves a picking station to the next picking place that needs the corresponding article.

This strategy proved to interrupt the throughput since the boxes had to visit several picking places and often were held up in the dedicated buffer lines.

The processing of batches with 8 boxes also was not very meaningful because the pickers have to wait too long for new orders. Thus, they are underutilised. For this reason batches must be reduced - an alternative would be to abandon the use of batch building strategies. The composition of batches also has the disadvantage that it loads the material flow system with small peaks. A further disadvantage arises as a result of the close linking of automatic and manual picking. It is often necessary to wait a long time for the boxes from the automatic picking and article boxes that were pre-picked in the manual area have to visit the picking cell twice.

- The store system reaches its operating efficiency limit as soon as the part of the return transfers of remainder boxes from order picking exceeds a certain threshold load. The problem becomes even more severe when articles to be returned into the store are administrated only in small quantities (boxes). The circulation of these boxes considerably delays the execution of picking batches.

Depending on the supply strategy for the picking zone, several remainder boxes can be generated so that the average box filling degree is reduced. In the end this can affect storage capacity availability.

The store system suffers from an unbalanced box input and output flow. Storage is practically permanent while stock removals have peak loads, especially when long tours are delivered. The simultaneous delivery of four boxes is used rarely so that crane movements increase considerably.

Peak loads also occur because the palletisers have to be assigned directly to predefined storage aisles. Thus control operations increase during storage and individual store blocks can be overloaded by the concatenation of unfortunate circumstances.

- The dispatch fails to reach the predetermined throughput. There are several reasons. Already the actual time to convey boxes to fill delivery buffers prevents dispatch from performing as efficiently as possible. The palletisers, however, have sufficient reserves.

This problem can be solved in general by refining the control concept which focuses in principal on sorting synchronization, buffer lanes and store systems.

Also the complete accessibility of all palletisers from all aisles of the store can be guaranteed through an additional conveyor technique. However, a serious disadvantage is that under unfavourable circumstances boxes must accept long conveying times (combination of remote storage aisle – remote palletiser).

The route table contains several routes which generate system loads that clearly exceed the technical capacity of the conveyor technique. This problem can be partly solved by reorganising the routes. However, the supply of boxes to the dispatch area has to be started very early in order to avoid peaks, so that customer ordering times (cut-off times) must be shortened.

The simulation technique has highlighted a series of weak points in the material flow concept. They involve to a lesser degree the conveyor technique and essentially the possibility of controlling the system. With the simulation suggestions are elaborated which alter the system's control and process organization, which also lead to a revision of the conveyor technical concept.

Finally, a concept was elaborated which fulfils all essential requirements of a distribution system. Without the simulation, crucial errors would remain within the whole concept which cannot to be controlled through simple means.

As a consequence, the operator would have had to accept a lower peak capacity.

5. Conclusions for further developments

At the present time, a paradigm change takes place in the planning and modelling of distribution systems: from a design of "throughputs" in which the conveyor elements are the starting point to a design that puts the focus on "mission fulfilment". Within this context the mission is the task for which a fully loaded truck leaves the ramp at a given time and carries along all corresponding customer orders.

- In addition, the "mission" concept gives the planner and supplier extensive freedom, but assumes that already in the conception phase far more than today is invested in control and strategies. There is interest in the efficiency of conveyor technique insofar as it must be able to handle dynamics, resulting from the strategies (to fulfil the mission).
- Without simulation techniques such a task can no longer be fulfilled as required. The simulation carries out several tasks:
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- Verification of the concept on logical errors
- Projects where complete systems have to be developed and where several persons are involved have to be integrated by the simulation. The technique provides the opportunity to check a database for consistency and to demonstrate decisions in terms of complete functionality.
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- Elaboration of control and process strategies
- A big unknown is always whether or not planned systems can in fact be controlled. In the rarest cases a system specification is provided with the bidding which describes processes in detail, although the relationship between investment volume technology and software has shifted significantly toward the software end over the last decade.
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- Often, a system which exhibits bottlenecks can still be operated with complex control. But experiences from many projects show that, in cases where complex controls in simulation have saved a system, in reality it is very difficult to implement such concepts. Ancillary conditions are often PLC technologies and compute-oriented factors, which haven't been throughout considered.
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- Project functionality
- Hardly any project remained within the given time and budget restrictions. And with ramp up doubts arise if and how the contractually guaranteed throughput can be achieved. If system simulation models exist, the crucial source of error or conceptual deviation can be found very quickly, so that ramp up times, which are often, and unfortunately, too short, can be brought under control. To examine the software there are special simulation-supported test environments, which can carry out very detailed deviation analyses.

Simulation technique often goes beyond the scope of delivery of the suppliers. It needs statements about personnel assignments, load scenarios, changes in the organizational operational sequence, the maintenance concept, and the liability of increases or extensions.

Therefore, the simulation models are delivered into the hands of the operator, as soon as a system is built, with delivery of the key, so that he can still react correctly in the future.

- Whether or not a distribution system will function does not only depend on the quality of planning, but also on the possibility of react appropriately to changes.
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- For further developments simulation software should provide special building blocks and distribution system modelling elements. There are long lists of elements that the tools need, such as:
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 - Means for assigning articles to storage areas
 - Design rules for storage systems, picking areas, consolidation systems
 - System operating algorithms
 - Algorithms for serving customers with different policies based on demand pre defined strategies, Available Goods and Reduction of Logistic Costs.
 - Algorithms for grouping shipping for Logistic Optimization and for Customers Satisfaction considering constrain
 - Rough calculations to check the results
 - Mechanisms for checking the models
 - Improved means for explaining results
 - Visualisation and animation tools, not only of layout-based components but also of data structures and operation rules
 - Appropriate optimisation techniques
 - Sensitivity analysis for new order structures
 - Robustness analysis for distribution systems where the utilisation is shared between different customers
 - Procedures for using simulation during acceptance
 - Simulation models as part of decision making in the life cycle of a distribution system
 - Model elements for operating distribution systems
 - Assistance during equipment construction and installation

The investigations regarding the future use of simulations in distribution systems must be concentrated on a general data basis in which simulation and asserting tools play an important role. Using the simulation is not only a task for the simulation community, it's also a task in which suppliers, major customers, consultants, and software designers, etc. have to work together. Through standardised interfaces the data can be used by all appropriate tools. Simulation software has to be modular in order to exchange model elements. Simulation application must be mandatory for consultants – in the end they will have to guarantee the correct performance of their designs.

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