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Sustainable Supply Chain - Supporting Tools

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Abstract— The most important topic for researchers is supply chain, that takes into account environmental factors and social aspects. That is why top managers prefer taking into account key performance indicators currently. Harmonization of social, environmental and economic components makes development of supply chains sustainable. This document is based on environmental protection; it details the main features of sustainable supply chain. It presents supporting tools of collaboration in sustainable supply chains. The main examined areas: system identification, order picking, inventory control systems, city logistics, intermodal logistics processes, routing, and logistics processes of earthwork. The tools: neural network, simulation, genetic algorithm, ant colony algorithm.

The paper is structured as follows: First chapter defines sustainability and Sustainable Supply Chain (SSC). The second chapter presents supporting tools of collaboration in sustainable supply chains.

I. Introduction, Environmental Protection, Sustainable Supply Chain

Environmental sustainability depends on the interaction between organizations in supply chain, products and ecosystems [1]. Sustainability is playing an increasingly significant role in planning and management within organizations and across supply chains [2], [3], [4].

Supply chain management is defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long term performance of the individual companies and the supply chain as a whole" [5].

Supply chain structure defines the way various organizations within the supply chain are arranged and related to each other. The supply chain structure falls into four main types [6]: Convergent: each node in the chain has at least one successor and several predecessors. Divergent: each node has at least one predecessor and several successors. Conjoined: which is a combination of each convergent chain and one divergent chain. Network: which cannot be classified as convergent, divergent or conjoined, and is more complex than the three previous types [7], [8], [9].

Sustainable supply chains are essential to sustain modern business growth and ensure healthy market environment [10]. In contrast to traditional SCM, which typically focuses on economic and financial business performance, sustainable SCM (SSCM) is characterized by explicit integration of environmental and/or social objectives which extend the economic dimension to the TBL [11]. In this context, SSCM focuses on the forward SC only [12] and is complemented by closed-loop SCM (CLSCM) [11], [12] including reverse logistics, remanufacturing, and product recovery [13].

Sustainable SCM is the management of material, information and capital flows as well as cooperation among companies along the supply chain while integrating goals from all three dimensions of sustainable development, i.e., economic, environmental and social, which are derived from customer and stakeholder requirements. In sustainable supply chains, environmental and social criteria need to be fulfilled by the members to remain within the supply chain, while it is expected that competitiveness would be maintained through meeting customer needs and related economic criteria. [4]

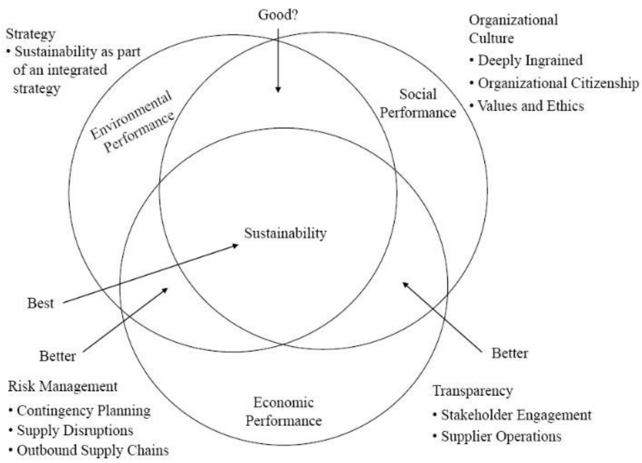

Fig. 1 Sustainable supply chain management [14]

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Carter and Rogers define SSCM (Fig. 1) as the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its supply chains [14].

In the article [15] the analysis reveals that six enablers 'Commitment from top management', 'Eco-literacy amongst supply chain partners', 'Corporate social responsibility', 'High level of supply chain integration', 'Waste management' and 'Logistics organisation ensuring goods safety and consumer health' are ranked as Independent enablers as they possess the maximum driver power. This implies that these variables are key barriers in the successful implementation of sustainability in the Supply Chain. The most important among them are 'Eco-literacy amongst supply chain partners', 'Commitment from top management' and 'Corporate social responsibility'.

Conceptualizing sustainability in three dimensions seems to be widely accepted [16, 17]. It allows an easy comprehension of the integration of economic, environmental and social issues. This also offers the justification of applying it in this paper. Most papers spend much more effort on explaining related environmental issues. In many cases, life-cycle assessment data forms the starting point for the analysis. Hence, energy demand and CO2-emissions (e.g. [18, 19, 20]) are among the frequently mentioned topics. Yet, in a number of cases, rather comprehensive lists of environmental impact criteria are taken up, such as referring to all kinds of natural capital (e.g. [21]) or resources, such as water or energy as well as waste (e.g. [22]) [4].

II. Supporting Tools of Collaboration in Sustainable Supply Chains

A. Automatic Identification, Neural Networks

In the last decade artificial intelligence (AI) methods come into prominence. The main reason is that the artificial intelligent methods are the mathematical models of human thinking and natural laws, therefore, a human-made decision support system (DSS) can behave similar way as an intelligent living being. With this ability the commonly used logistics methods can be developed in different fields such as planning and operation. In some cases the human intelligent can be swapped or complemented with artificial intelligence methods [23]. These methods could be inventory, scheduling, shortest route problems. The main purpose of [24] is to develop a time series analysis method in order to increase the demand forecast accuracy. The examined method is the Autoregressive Integrated Moving Average (ARIMA) model [23], [24], which has outstanding forecast accuracy in case of an auspicious identification. The aim is to show that the automatic ARIMA function identification can be accomplished with an artificial neural network (ANN) and with its learning ability the efficiency of identification is growing, see Fig. 2.

The automatic ARIMA (p, d, q) model identification described in [24] is a result of a continuous research and development. It was presented that the current identification methods and tests are hardly usable for "non ideal" time series and they are unable to adapt to the constantly changing characteristics of input data. On the other hand the model identification with a neural network is less sensitive to input errors through its intuitive capability, additionally after a certain number of training steps the algorithm is able to identify time series with unknown characteristics.

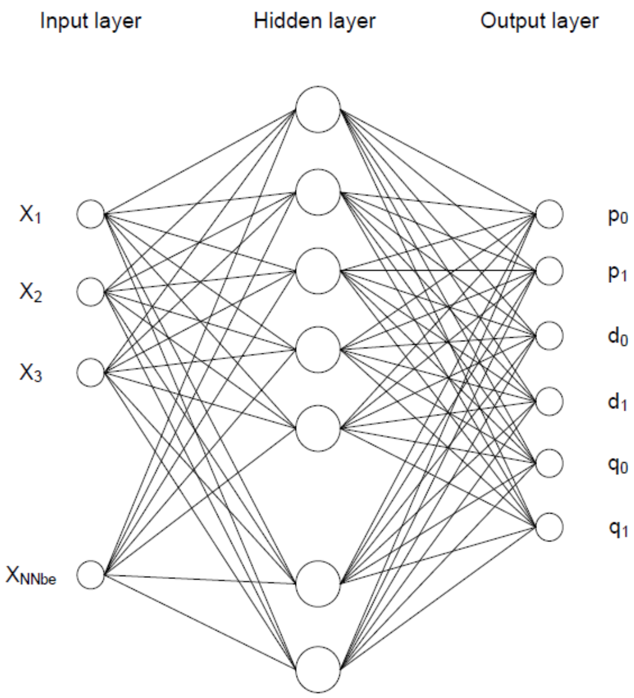

Fig. 2 Neural network [24]

These features make the method capable of integrating it into logistics processes. Of course the presented forecast method [24] is applicable to support other problems. The learning and intuitive capability of the artificial neural network is usable on any fields, where a prompt decision must be done with the support of previously acquired knowledge. It is effectively applicable solving inventory, scheduling, shortest route problems. The accuracy and efficiency of the method highly depends on the previously acquired knowledge, therefore, a great importance must be attached to the planning and operation. If the attention is made then the result is a robust, fast and flexible system wherein the unknown and random events can be treated effectively.

B. Multi-criteria Scheduling of Order Picking Processes with Simultan Optimization

The flexibility of labour in a warehouse means that available personnel are redeployed during shifts to activities (storage, order picking, replenishment, etc.) where extra capacity is required. In the case when available labour capacity is not sufficient, temporary staff can be hired from specialized agencies. Order picking – retrieval of products from storage to meet customers' demand – is often the most labour-intense activity in a warehouse. The human hand as a 'handling equipment' is hard to be replaced and economical automation of retrieval of products is seldom possible. Therefore, the costs of order picking may amount to about half of the operational costs in a warehouse, so any improvement in this field may result in significant cost reduction [25, 26, 27, 28].

Both optimization and simulation are tools that support decision making. Optimization uses fixed input data, avoiding uncertainty and details. Optimization models simplify the complexity of the real system and some factors are even not considered. The simulation is not creative like optimization, but can cover uncertainty and complexity of dynamic systems in detail. The combination of optimization and simulation (simulation optimization) can be defined as the process of finding the best set of input variables without evaluating each possibility. The objective of simulation optimization is to minimize the resources spent (i.e. time) while maximizing the quality of information gained in the experiment. The model represented in [27] also uses the benefits of simulation optimization. The designed system supports operative warehouse management personnel in order to pick process scheduling and planning. By evaluating a number of scenarios, the number of the order pickers per shift, and the best sequence of releasing the pick lists to be retrieved from storage are determined [27]. It is the management's responsibility to monitor and control the order picking activities in the warehouse continuously and force the adherence to the schedule. If all order picking activities are realized according to the schedule, then the planning of the replenishment of the order picking places is also possible. The goal of [27] is to further develop the above described planning system and include the scheduling of these activities, too. The connection to the database of the WMS with the simulation model already exists so it is possible to determine when the last products will be picked from each picking place and when replenishment is necessary. By applying advanced search methods – like Genetic Algorithms – the optimal schedule for the replenishment of the picking places can be evaluated. The objective function must reflect the goal of planning the replenishment process so that the order picking processes can be executed continuously and undisturbed – products are available at the picking place and the congestion in the aisles is avoided. It is also the object of further development to improve the optimization algorithm and reach higher speed and accuracy in calculation. In this first version of the model [27], all probabilities to execute each genetic operator were constant. The proposed development (Fig. 3) will operate with variable probabilities for crossover and mutation to inherit the properties of the fittest individuals into the next population, to avoid premature convergence and to close-up the search space [27], [29].

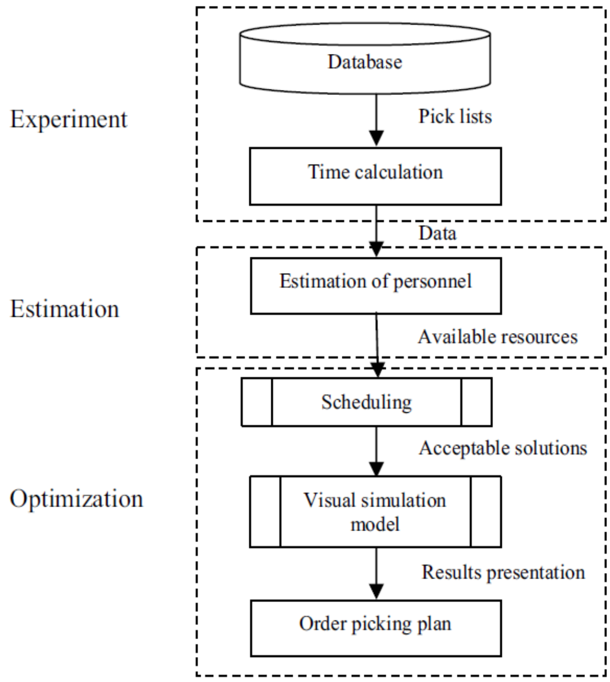

Fig. 3 Scheduling and decision support process for order picking planning [27]

C. Optimization of Inventory Control Systems with Genetic Algorithms

The inventory control systems are responsible for the optimal operation of the inventory processes of the automotive companies. Generally, the optimization of the inventory control system manifests itself in a target conflict representing the implementation of the optimal operation in economic and reliability terms. For the process optimization, the control parameters of the regulation system should be defined. Their actual settings determine the time of placing orders of auto parts and the required quantities for the optimal operation of the processes defined above [30] presents a particular method of exploitation of the opportunities provided by the computer aided simulation and the genetic algorithms for the optimization of inventory control systems applying classical inventory mechanisms (Fig. 4).

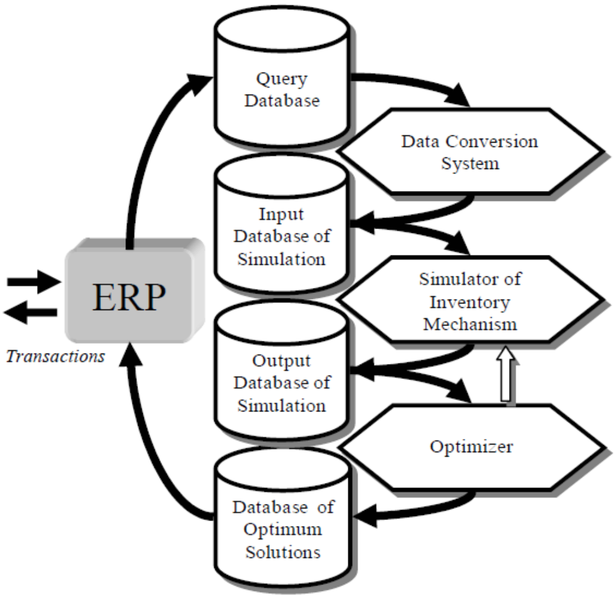

Fig. 4 Process of the dynamic inventory management [30]

The simulation inventory model presented in [30] and the binary genetic optimizing algorithm determining the control parameters showed beneficial properties in managing of stochastic inventory processes. For the establishment of proper applications, it is worthwhile to examine also the services rendered by the genetic algorithms operating with real number representation, as it is possible that this type of algorithm is able to provide the same results in a faster, more accurate way. Experiences show that the inventory processes in the future may constitute a special application field of the simulation supported optimization with genetic algorithms.

D. CITY LOGISTICS: DIFFERENT APPROACH, MODELS

The urban travel and land-use problems are not just urban problems. Their economic, social and environmental impacts extend well beyond the geographic jurisdictions of cities and towns to regions and to countries as a whole. The policies are designed to shape travel and land-use patterns to maximize the benefits of transport while minimizing their negative impacts. Given the broad spectrum of economic sectors and actors potentially impacted by urban travel and land-use activity, a package of complementary policy instruments needs to be developed that provides clear and well-targeted incentives to reduce the impacts of urban travel and land-use activities. This involves better integration of land use and transport planning. It involves finding ways to manage growth in car use and ensuring that alternative modes of travel by car – public transport, walking and cycling – are promoted. Fiscal and pricing instruments, legal and regulatory tools, currently available technology, and public information are some of the main policy tools available. A policy framework that embodies clear long-term objectives for urban travel may provide the essential parameters for implementation of integrated sustainable urban travel policies [31], [33].

By city logistics, we mean the technically, economically, organizationally efficient and environmentally friendly synchronization of goods distribution (and reverse logistics) tasks generated mainly by the secondary and tertiary sectors, and mostly retailers in downtown areas and historical city centers. There are many best practices to be found worldwide, that have already been identified and classified. Different city logistics system solutions affect the goods distribution of a city in various ways and magnitude, thus a model is desirable that helps the decision-making of stakeholders. [34] Is examining the indicators of cities housing city logistics system solutions, and some that are lacking those. The problem with the latter is that the shops, that form the demand scattered throughout the city, are not visited by their suppliers in a coordinated fashion, taking advantage of the common capacity, but rather they compete. Satisfying the demand takes place with presumably sub-optimal logistics-related costs [35]. This comes from the different suppliers transporting same types of goods to the same destinations with different – redundant – infrastructure, which could be avoided, according to [36]. Moreover, the attributes of the supply chains are adjusted to the regulation of the given municipality, but they seldom take advantage of certain possibilities (e.g. river, railways), and usually do not utilize integrated solutions, preferring road to multimodal transportation [32].

In order to assess the possibilities, [34] is developing a model that can compare various scenarios. The model is constantly evolving, but its fundamentals are: it maps an area with a graph, generates variable demand, and compares total costs. The model is basically static in structure: the different alternatives are constituted by nodes, and the transport system between each of these nodes. The demand is stochastic: the destinations and their daily demand (quantity of goods ordered) is a random variable. The total demand has to be satisfied with a – a priori unknown – number of vehicles. The common elements of the solutions are the location of the suppliers (LS), the urban consolidation centres (UCC), the urban relay stations (URS), and the urban loading points (ULP).

The number and location of these varies with each alternative. Further variable elements are the local and regional transport systems, with different vehicles and tracks. Accordingly, the model consists of a network, modelled as a graph. This structure of the model is suitable for the present and the planned systems, so they can be compared (Fig. 7).

The greatest challenge that can help the application of the model is the acquisition of more precise unit costs derived from logistics performance. External costs should later be included next to the existing ones, because a primary goal of a city logistics system solution is the reduction of the air and noise pollution and the augmentation of the standards of living. The fine-tuning of the model should produce precise enough results that can point out an advantage of a specific alternative. The model, since it was developed generally, can be used extensively and in a wide number of cities and urban areas: the model parameters can be modified so as it can help decision-making at different locations [34].

Element	Type	Vehicle	Function
Location of suppliers (LS)	Node		Source of goods
Long-distance transport paths	Edge	Regional vehicles	Large-scale, homogeneous goods transport
Urban consolidation centres (UCC)	Node		Consolidation
Main urban transport paths	Edge	Local vehicles	Large-scale, heterogeneous goods transport
Urban relay stations (URS)	Node		Fast transhipment
Feeder urban transport paths	Edge	Last mile vehicles	Small-scale, heterogeneous goods transport
Urban loading points (ULP)	Node		Sink, points of sale

Fig. 5 Elements of a city logistics network [34]

As further possibility, in general terms, electronic freight and warehouse exchanges are virtual market places established for the harmonization of freight demand and supply. Due to their characteristics, however, these may be also suitable for the division of capacities (capacity load and storage capacity) of certain freighters and forwarders. Upon these trade directed to cities may be optimized, as groupage transport may be organized to cities, or within these to districts, considering, at the same time, the possibility of acquiring back haul, as well. In addition to this, by the division, optimal exploitation of freight capacities trade directed to the cities may be significantly reduced with the application of a transfer location in the outskirts of the city and a related warehouse exchange [36].

To effectuate a consistent methodology for urban planning – taking into consideration the viewpoints of land use and transportation – we need to approach the subject with considering complex social and economic aspects. To handle both of the mentioned urban planning areas together, we shall develop models, which are able to pay attention to all of their restrictive factors within the temporal properties as well. The efficiency of urban transportation is getting more and more important because of the increasing rate of mobility demand. To plan, control and organize urban transportation in the most efficient way, we also need to consider the aspects of land use. [37].

E. INTERMODAL LOGISTICS PROCESSES

The role of the intermodal logistic processes and related services are continuously changing and developing due to the spreading of transportation processes. One of the most frequent attribute of the service functions is the implementation parameters (for example place and material requirement) which are being changed, so the logistics system must be able to follow its flexibly. Because of the complexity, at any given time and location the implemented service requires cooperation between multiple logistics subsystems which are connected together only with the common management system and the endpoint of materials flow. One of the possible surface to satisfy the ever growing and changing claims if these services are supported by electronic freight and warehouse exchanges to perform the logistics processes.

The modified supply chain by electronic freight and warehouse exchanges is shown in Fig. 6. The main features of the modified supply chain system:

- The wholesalers are responsible for the information processes; they manage the demands of retailers.
- The logistics providers (storage providers, transportation providers, logistics centres) perform the physical freight and storage tasks, whereas they have:
  - o suitable stock capacities,
  - o suitable freight capacities,
  - o logistics know-how.
- Electronic freight and warehouse exchanges perform the supply-demand (capacities-tasks) harmonization; the decision supporting and the optimization.
- In the case of logistics providers and electronic freight and warehouse exchanges the logistics processes are core.
- Due to the above the modified logistics system (e.g. combined transportation system) may be optimal.

Consequently, green logistics systems, e.g. green combined transportation supply chains can be realized (Example can be seen in Fig. 7). In addition, this system is beneficial not only for the individual actors (e.g. retailers, wholesalers, logistics providers, manufacturers, intermodal centres) but also for the national economy. The future plans include further development of algorithms and tests in real supply chains, e.g. supply chains of drink industry or other possible combined or complex city transportation system.

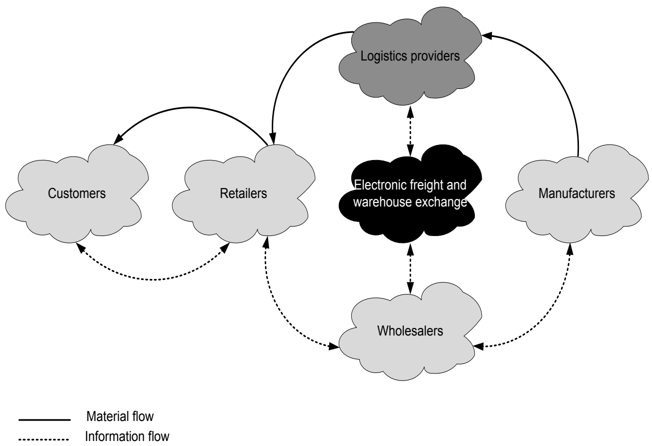

Fig. 6 The simplified system model of the supply chain supported by electronic freight and warehouse exchanges [38]

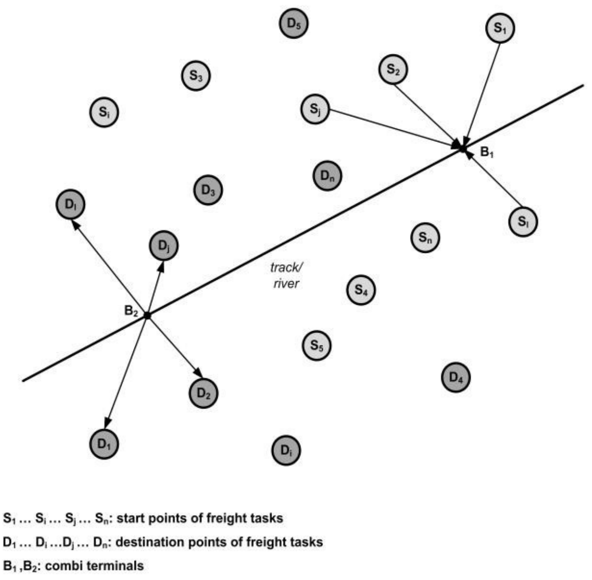

Fig. 7 Multimodal transportation supported by freight and warehouse exchange [38], [39]

F. Routing (TSP, VRP) in electronic freight and warehouse exchanges with ant colony algorithms

The basic function of electronic freight and warehouse exchanges is to establish connection between free freight and storage capacities and tasks [40]. In the database of such online fairs there is high number of freight and storage capacity offers and tasks, which provides good optimization opportunity for those with free capacity [42].

The Vehicle Routing Problem (VRP) is used to design an optimal route for a fleet of vehicles to service a set of customers' orders (known in advance), given a set of constraints. The VRP is used in supply chain management in the physical delivery of goods and services. The VRP is of the NP-hard type [41].

In the freight exchange the optimum search task may be formulated on the basis of the following objective function: those having free freight capacity wish to establish routes providing optimal profit from the freight tasks appearing in the freight exchange. Many freight tasks may be included into the route, but a new freight task may be commenced only after the completion of the previous one.

The ACO (ant colony optimization) is an optimizing algorithm, a method developed by Marco Dorigo based on the modelling of the ants' social behaviour. In nature ants search for food by chance, then if they find some, on their way back to the ant-hill they mark the way with pheromone. Other ants – due to the pheromone sign – choose the marked way with higher probability instead of accidental wandering. Shorter ways may be completed quicker, thus on these ways more pheromone will be present than on longer ones. After a while the amount of pheromone drops (evaporation), by this preventing sticking to local optimum [42, 43].

In the electronic freight exchange similar problem emerges as the ants' search for food: the target is the performance of freight tasks offering the higher route level profit departing from the depot of the vehicle, with taking into account the limiting conditions. The problem, therefore, is twofold: on the one hand, the freight tasks to be performed shall be selected, and, on the other hand, their order shall be defined (FB_ACO, Fig. 8).

In the electronic warehouse exchange the task is simpler but is still similar to the food search: storage tasks shall be selected by taking into account storage capacity, possibly with the best possible exploitation of capacity (RB_ACO, Fig. 8).

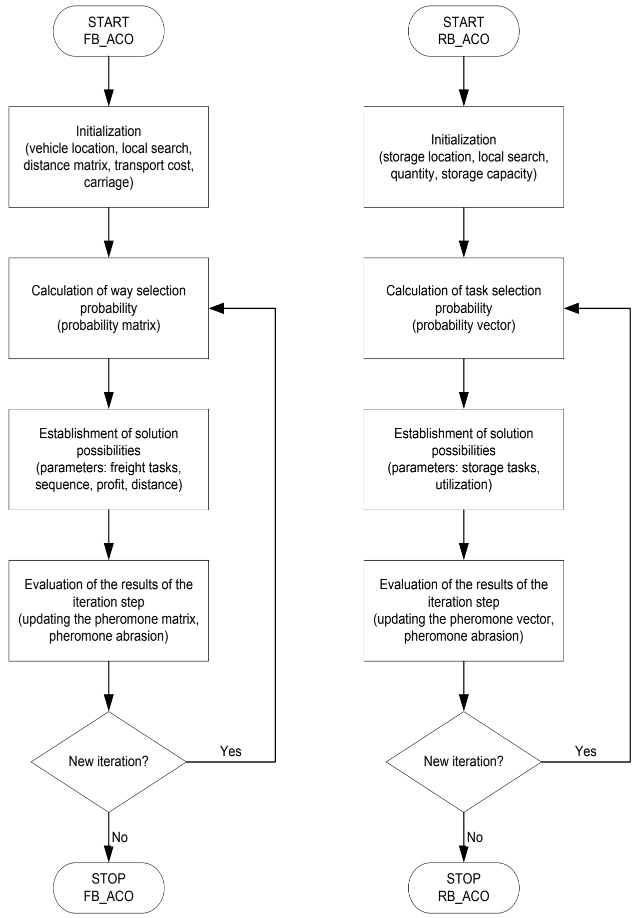

Fig. 8 The developed ant colony algorithms (FB_ACO and RB_ACO) [42]

G. Simulation in earthwork model and its logistics processes

Vehicle-based transport systems using automated guided vehicles (AGVs) are commonly used in facilities such as manufacturing plants, warehouses, distribution centers and transshipment terminals [44]. They are referred to as automated guided vehicle systems (AGVSs) [41], [45]. Early AGV systems were developed at universities and research institutes, named commonly as mobile robots. Later the industry realized advantages of autonomous transport vehicles for repeating transport tasks. One main application area for AGVs is the intralogistics or manufacturing logistics, where the vehicles are mainly used for transporting raw materials, half-ready parts and ready products. These automated systems became moreover integral part of automated manufacturing systems as pointed out in [46]. The other important application is the automated container terminals, where AGVs transport various sized containers between the quay and the stacking area. More detailed system description find in e.g. [47]. Automation comes forward in other application areas as well [48]. Presents an automation example of a mobile excavator. The paper describes a pilot project investigates how autonomous functions could be realized on a mobile wheeled excavator. Rough terrain which characterizes construction sites however makes use of automated vehicles difficult [43]. Is aimed to help automation processes at the construction industry [43]. Concentrate on the logistics aspects, where organization of the material flow is an important task. The main of the focus of [48] to presents an automated soil transport system's simulation model which can be used to prove that intelligent systems may help construction processes as well. For the implementation agent-based approach is used.

[43] is organized as follows. First a short summary is given about the applicability of agent-based approaches. Next it describes which components or agents should be defined in different material flow systems using AGVs. In the following section detailed concept is presented for the implementation of the agent-based model for an earthmoving system (Fig. 9). Finally some remarks are made about the model's implementation in simulation environment.

The paper [43] surveyed applicability of agent-based principles for modeling material flow systems. An agent-based simulation model is also proposed. This model can be used for material flow systems' analysis not only for the case when each machine operates automatically, but due to the complex behavior for cases when the machines are operated through human workers. The proposed model is due to its modular construction can be adapted for different applications easily. Next step of the research is to build in so called information modules, which model information flow of the construction processes.

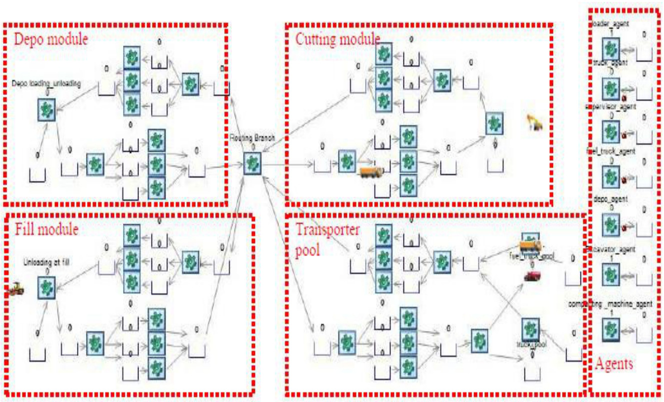

Fig. 9 Simul8 implementation of the proposed earthwork model

III. CONCLUSION

In this survey paper, there are several examples to optimizing the intra and extra logistics processes to. Automatic identification, neural networks, genetic algorithms, ant colony algorithms help find the optimal solution, and thereby to optimize the use of resources (e.g. human, material handling machines, transport machines, transport routes etc.), and to reduce the pollutants. Thus, sustainable supply chains can be realizing, that means economic and environmental efficiency too, whether it be city logistics supply chain, order picking processes or even earthwork.

We think that this topic deserves extensive additional research. Management studies and environmental science need to bridge the disciplinary distance that until now has characterized the two fields. There is a great need and urgency for further progress, and management theory must investigate the complexity of the relationship between organizations in supply chain and nature in order to support firms in the development of effective environmental strategies [49]. In this paper, we have stressed the importance of a holistic perspective in the service of sustainability. We argue that the individual firm is not the right unit of analysis for assessing environmental progress. Companies have many options to reduce their impact at the single organizational level (from clean technologies, to ecosystem restoration). But global ecological problems are not the result of a single firm's action. Ecosystem complexity over spatial and temporal scales requires close involvement and coordination across supply chains and industries as the appropriate unit of analysis for facing environmental problems [50,51].

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