A Case for Material Handling

Systems, Specialized on Handling

Small Quantities

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Abstract

Operation Principles for Material Handling Systems have traditionally tried to find a balance between economies of scale by combining as many orders as possible (for instance in batch and wave picking, combining loads to save transport costs etc.) and by achieving good customer service by starting work on the orders early enough. Based on previous work on modelling of batch operations, we will show the impact of batch building on the performance of operations in terms of throughput time and resource consumption.

With an example of parts supply for an assembly operation we will show, that the impact of batch building on the reliability of throughput times is larger than expected. Therefore it seems to make sense, to create material handling systems, which are more suitable for an economic handling of small quantities of goods. The technological advances in the last ten years enable us to build such systems if the design of the system elements and their aggregation into larger systems is changed considerably compared to nowadays systems architecture. We will present a future architecture for material handling systems, which relies on a multitude of smaller modules, which integrate

energy storage and generation, actuation, sensors and control. By combination of these modules larger tasks will be solved while always working on small quantities of goods at one moment.

The Material Handling Task to be Solved

Many tasks in material handling are usually solved by accumulating orders and parts in batches and transporting them accordingly. The reason for doing this is that transportation and storage is often easier done in large quantities than in small batches. One reason is that the standardisation of large bins (at least in Europe) is much more advanced than that for small bins, which in turn results in ubiquitous material handling and storage equipment for Euro-Pool pallets, drop-side mesh pallets and similar devices.

Since material handling equipment like forklift trucks and pallet jacks are widely available, a logical consequence is to use this equipment and in order to do this economically, to batch the items to be transported accordingly. This can be a good solution but there are cases, where it is very beneficial, to be able to independently move small quantities efficiently.

If single items and bins have to be moved, usually continuous material handling devices like belt or roll conveyors are used. This requires however fixed installations and investments, which are tied to a specific application, which only pays off if a large volume of items or bins has to be moved and the equipment can be used over a longer period of time with hardly any changes. Especially in manufacturing or packaging operations the processes and thus the environment is usually very unstable, which makes the installation of conveyors and similar equipment impractical.

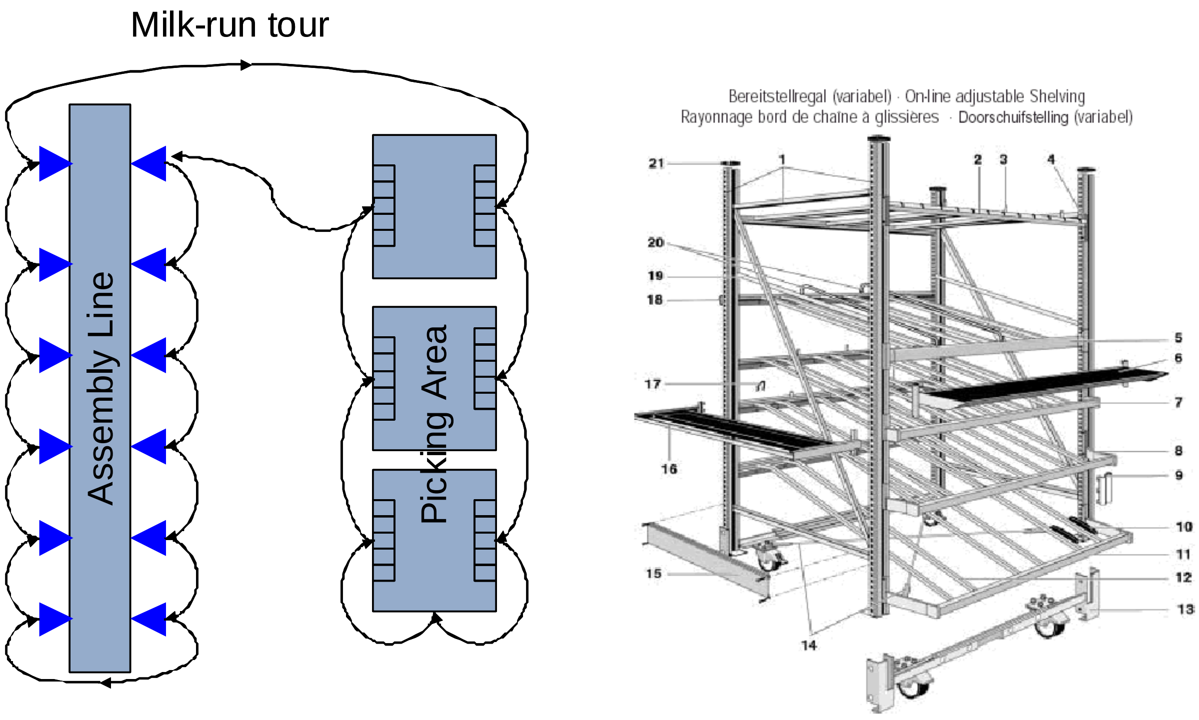


Figure 1: Example of an assembly system with small parts supply in flow rack

We present a small example of a car assembly line, where small parts are supplied to the line with a Kanban-pull system. The bins with the parts are stored in flow racks (see figure 1, right) at the line, where the assembly worker can easily pick them up and use them for assembly. In regular intervals, a milk-run makes its tour, picking up the empty bins and kanbans while providing replenishment of those bins, which have been provided from the picking area.

The kanbans are then dropped of at the picking area, where either the milkrun driver or a designated picker is picking the required bins from the shelf and prepares the for the next milkrun tour.

The bins are then loaded onto the milkrun train and subsequently distributed to their positions at the assembly line.

The shelves at the line have to store enough bins in order to make sure that the supply at the line is sufficient with a very high probability. The necessary space is minimized, when every single kanban is transmitted immediately and every single bin transported instantly. However, in practice milkrun trains are used and batches of bins and kanbans are transported. This reduces the transport cost but increases the necessary storage space in the shelves at the line, since the time used for batching and the higher variability of the arriving kanbans which represent picking orders at the picking area creates a higher waiting time for picking orders there.

In order to study the effects decisions affecting batch size and frequency of milkruns n the shelf space, a discrete time model is used.

The Model in Discrete Time

Using discrete time models for material handing systems (see [2]) makes it possible to study the effects of batch sizes and process time variability not only with respect to the mean throughput time but also with respect to the percentiles of the distribution of the replenishment time.

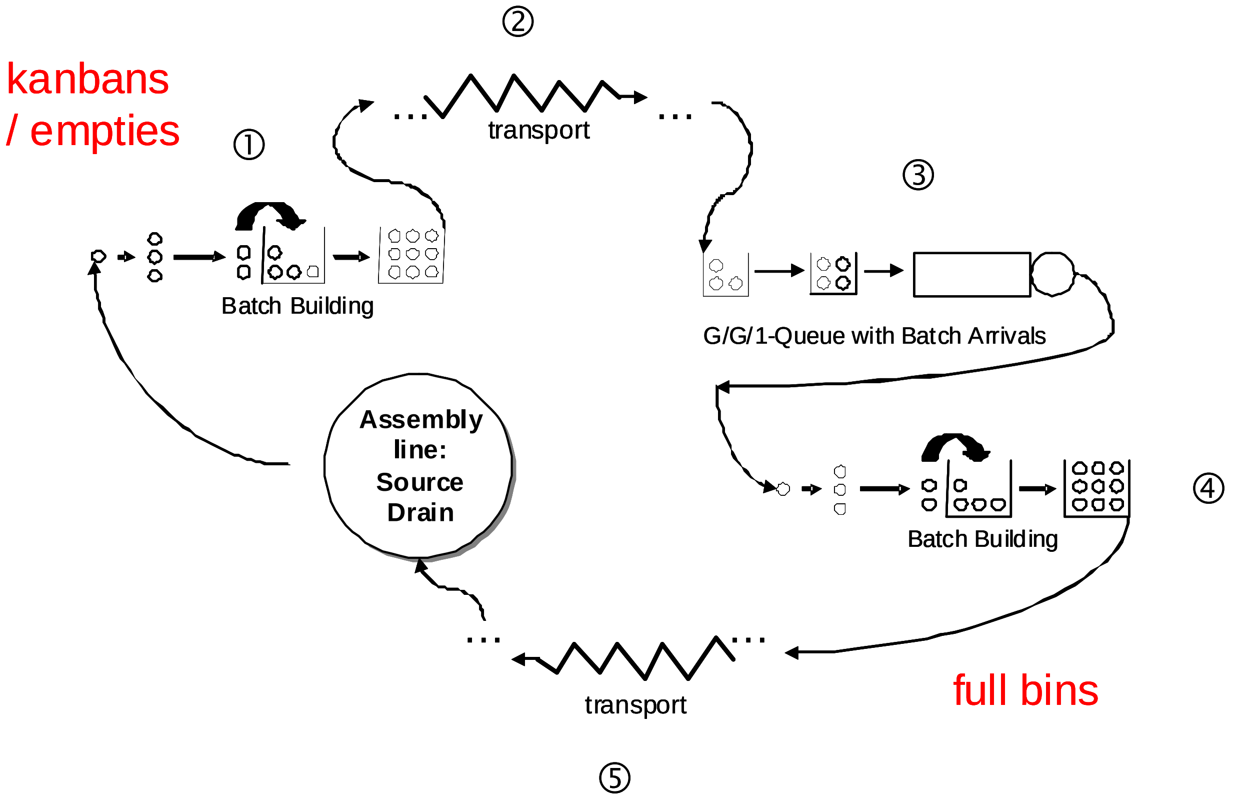


Figure 2: Model of the Assembly Line and the Supply Process

Since milk runs are operated in regular intervals, the first step (1) models the batching process of collecting kanbans for a specific time interval. These kanbans are then picked up and transported (2) to the picking area. Assuming, that there is exactly one person picking, the picking process is modeled by a G|G|1-Queue with batch arrivals (3). After picking, the transport of the bins is again done in batches, occurring in fixed time intervals (4) and after a transport time (5) they arrives at their destination.

Computational Results

For the analysis of the supply process we use discrete time models which we developed in our earlier research work. The sojourn time distribution for all processes of the underlying assembly system can be calculated. This leads to the replenishment time distribution.

The interarrival time distribution of empty bins (which means kanbans) at the assembly station, the picking time for filling an empty bin, and the transport time for travelling between the assembly line and the picking area are given.

For the analysis of the batching process we developed an approach presented in [3], in which we use renewal theory to determine the number of collected kanbans and the sojourn time of an arbitrary kanban.

The time between the arrival of kanbans at the picking area and the departure of filled bins consists of the waiting time of kanbans at the picking area and the order picking time. The waiting time distribution of an arbitrary kanban can be calculated by the G|G|1-Queue with batch arrivals introduced by Schleyer and Furmans [2]. This approach consists of two steps. First, the waiting time of the whole batch of kanbans at the picking station is determined. Using difference between the incoming work (time required to serve a batch of kanbans) and the outgoing work (time which is provided until the arrival of the next batch of kanbans) the well known Lindley's equation in discrete time can be set up. Grassmann and Jain provide in [1] an efficient algorithm to solve Lindley's equation which is based on the Wiener-Hopf-Factorization. In the second step, the waiting time of an arbitrary kanban during the service of a batch of kanbans has to be considered. This can also be done by the method of Schleyer and Furmans [2]. Then, the sojourn time distribution of a kanban within the picking area is calculated by the convolution of the waiting and picking time distribution.

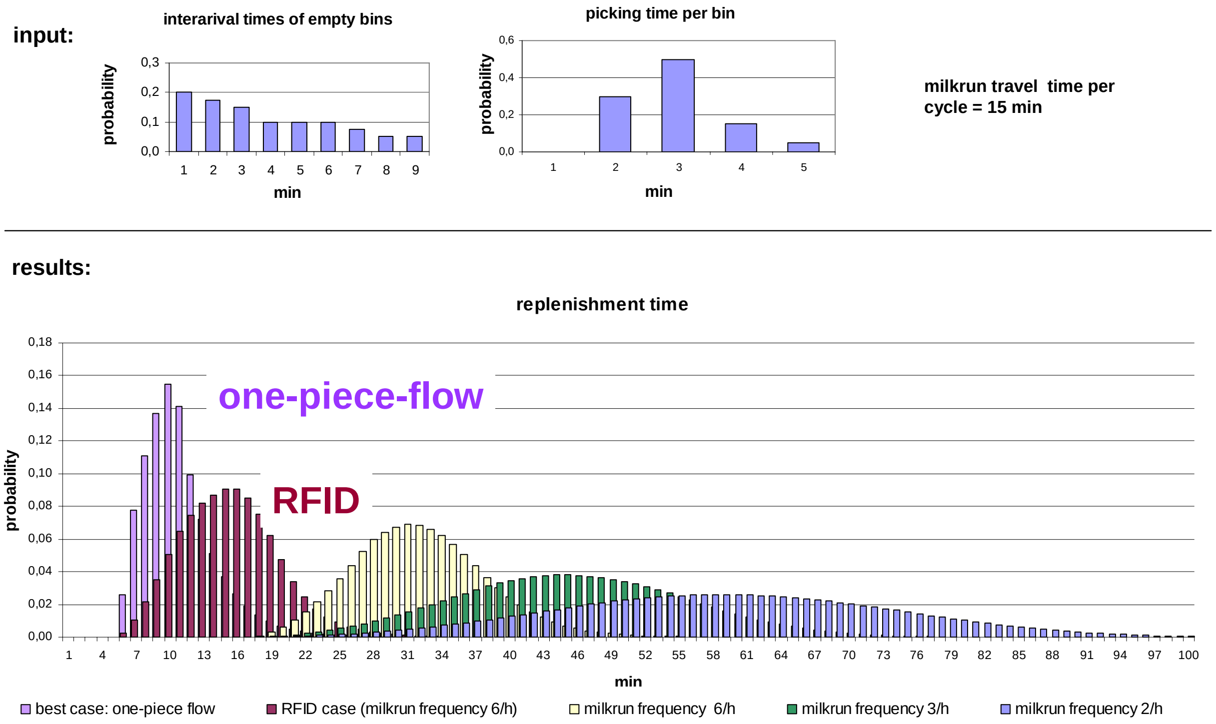
Next, we calculate the interdeparture time of served kanbans (which means filled bins) from the picking area. Given the interdeparture time distribution, the number of bins which has to be transported to the assembly line, and the sojourn time of filled bins at the batching station can be determined.

Finally, the replenishment time distribution is given by the convolution of the distribution of the sojourn time of the above named processes.

In a numerical example the replenishment time distribution is determined. The replenishment time is analyzed in dependence on the frequency of milkruns resulting in different batch sizes (see figure 3). The required time frame which guarantees the on-time replenishment of material with a given probability (e.g. 99%) decreases considerably with an increasing frequency of milkruns which means smaller batch sizes. Furthermore, figure 3 shows that the probability of on-time replenishment reacts more sensitively to parameter changes than the mean replenishment time.

Moreover, the replenishment time can be reduced if the picking area is instantly notified that a bin is empty. This can be enabled by RFID-technology. When a worker at the assembly line empties a bin and removes this bin from the flow rack, a RFID-chip which is attached on the bin recognizes that material is required. An order is transferred immediately to the picking area. The red coloured histogram of figure 3 shows the replenishment time distribution of the RFID case. The cycle time reduction is clearly apparent.

Finally, the best case is discussed. It is assumed that replenishment orders are instantly transferred to the picking area by means of RFID-technology and full bins are transported instantly after picking to the assembly line. Since replenishment orders arrive singly at the picking area and full bins are transported singly to the assembly line, a one-piece flow is realized. The replenishment time for the one-piece flow is illustrated by means of the purple histogram in figure 3. This is the minimum possible replenishment time of the presented numerical case.



	best case one-piece flow	RFID case milkrun frequency 6/h	milkrun frequency 6/h	milkrun frequency 3/h	milkrun frequency 2/h
mean value	10,03	14,51	31,21	44,49	57,87
95%-Quantil	11,00	22,00	41,00	61,00	82,00
99%-Quantil	14,00	27,00	47,00	68,00	92,00

Figure 3: Numerical results: The effect of increasing milkrun frequency, use of RFID and implementing of a one-piece flow on the replenishment time

If the replenishment time distribution for a specific system configuration is known, the required stock of material can be determined (see Tempelmeier [4]). Thus, the replenishment time distribution is a crucial precondition so that different system configurations can be evaluated. Then, logistic planners are able to decide about the profitability of milkrun frequency increase or the investment in new technology such as RFID.

The Technical Challenge

The determined requirement to provide efficient single transports and efficient batch transports and the fact that today's production and logistic processes change frequently demand modern material handling systems with a maximum flexibility. This implicates maximum flexibility in goods/bins, maximum throughput flexibility and maximum layout flexibility. Since the realization of such material handling systems can't be realized with state-oft-he-art conveying technology a completely new architecture of material handling systems must be developed. Figure 4 shows a possible architecture of a modern material handling system.

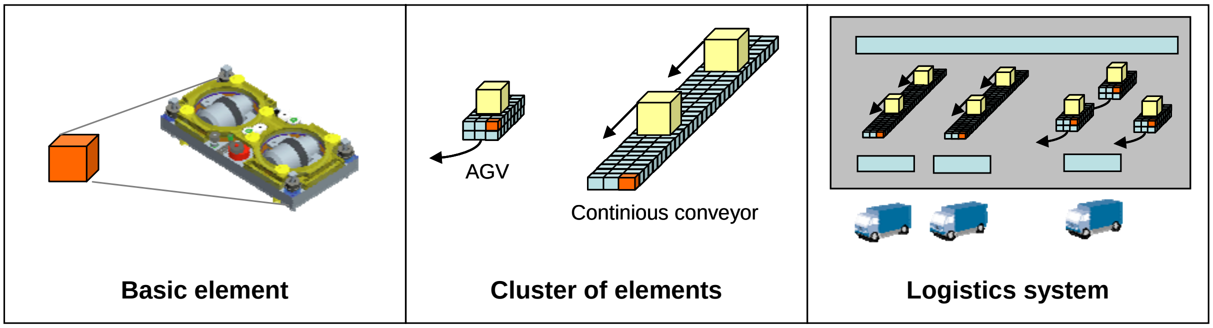


Figure 4: Future architecture of material handling systems

The system consists of basic elements which are able to perform elementary functions or tasks on their own, e.g. basic function concerning the element's "life functions", like energy management, or even tasks like the transportation of the smallest bin in the system. To perform more complex tasks the basic elements aggregate to function-clusters. The clusters' functionality can correspond to conventional conveying systems like AGVs (Automated guided Vehicle) in different dimensions or conveyors with continuous operation mode.

Besides the flexibility (in layout, throughput and goods/bins) a system with the described architecture combines further advantages compared to conventional conveyors: The high (and cost-intensive) reliability of single components is exchanged by high reliability due to redundant elements. The system is scalable. Systems can be reconfigured to adjust the material flow to the changing processes instead of breaking it down and rebuild it (layout and throughput flexibility).

The performance of the introduced system is predominantly depending on the characteristics of one single basic element or maybe several different basic elements. The basic elements influence the practicable scale factor and the functional range of the system.

Considering standard bin sizes the setting of the system's scale factor must be a compromise: A typical storage bin with Euro footprint (600x400mm) and a maximum load of 60 kg has a specific load of 250kg/m^2, while a Euro-palette (1200x800mm, 1200kg) has a specific load of 1250kg/m^2. The resulting size-scale-factor would be $\text{palette/bin}_{size}=4$ and the load-scale-factor would be $\text{palette/bin}_{load}=20.8$, so the scaling can't be optimized for the size and the load of bins and pallets at the same time. A wide functional range can be enabled by either a variety of specialized types of basic elements or one universal basic element. In a system based on a variety of specialized element types the element costs are lower than for a universal element while the total amount of specialized elements exceeds the total amount of elements in a system with only one element-type.

Yet the described system is theory but how far away from an implementation is science and technology? To develop the basic element we have to deal with the main disciplines shown in figure 5.

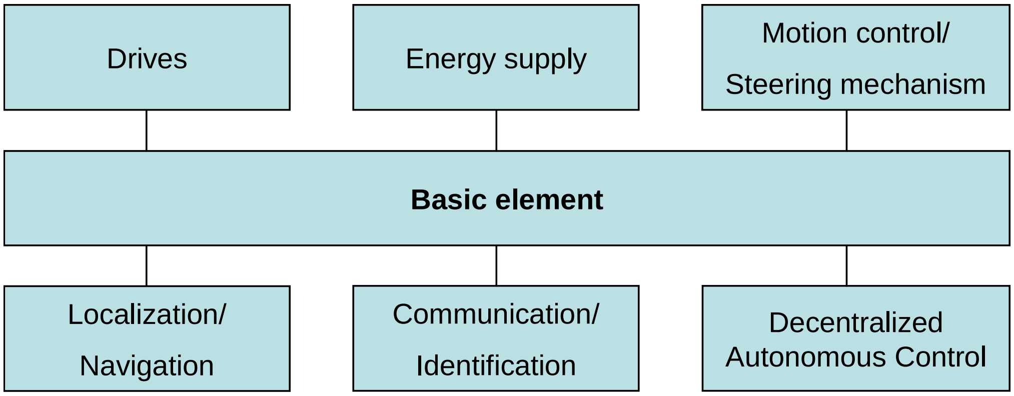


Figure 5: Main disciplines in realising future material handling systems

The system's drives and energy supply are mainly responsible for the power-to-weight-ratio and the power-to-volume-ratio and therewith for the dynamic and the efficiency of an element and it's dimensions. Only with compact and powerful basic elements a high system performance at acceptable energy costs and an expedient scale factor are possible. For full functionality the basic element may include up to eight drives for travelling, conveying, lifting and if necessary for mechanical element coupling.

The energy supply must ensure a permanently operating system at an efficient energy transfer to drive controls, drives and on-board-hardware.

To aggregate the basic elements to clusters and to steer the clusters the elements must possess a coordinated motion control and a steering mechanism that allows a cooperative transport of goods. A coupling of the elements during the coordinated transportation is possible by friction to the cargo or by a mechanical coupling mechanism.

For a maximum layout flexibility and as a precondition for coordinated travelling and navigation the single element must be able to detect its actual position. The typical industrial environment contains racks, machine tools, other basic elements, ... – all parts that may cause interferences and failures in electro-magnetic localization systems. A further challenge in localization is the dynamic surrounding area with moving humans and further elements.

In a Material handling system of the introduced architecture the two major tasks of communication are to transmit information from and to a central host and the communication between the vehicles and between vehicles and goods/bins including the identification of goods and vehicles. The influence of the industrial environment and the amount of communication partners may affect the robustness of the system.

To provide the required flexibility, especially layout flexibility, the introduced system architecture implicates a decentralized controlled system of autonomous agents. The algorithms for control and cooperation must be implemented in the hardware of each element. If one takes in consideration that multi robot systems of 100 robots or more never lasted for more than a few seconds it is a great challenge to control a nowadays system with the above architecture in a decentralized way by autonomous basic elements.

Opportunities

The variety of different technical issues that must be considered in order to realize a future material handling system is a challenge and an opportunity at the same time regarding the technological advances of the single issues in the last ten years.

Looking at drives for example modern brushless DC-Motors, compact semiconductors in drive controls have the power density that enables the design of miniaturized vehicles with high power-to-weight- and power-to-volume-ratio. Figure 7 (left) shows a photo of the mechanical assembly of our first BInE (Basic INtralogistic Element). At a size of 460x200x90mm (LxWxH) and a total weight of 15 kg it is able to carry and lift a load of 250kg and accelerate it with a power of 960 W (two brushless 480W DC-motors).

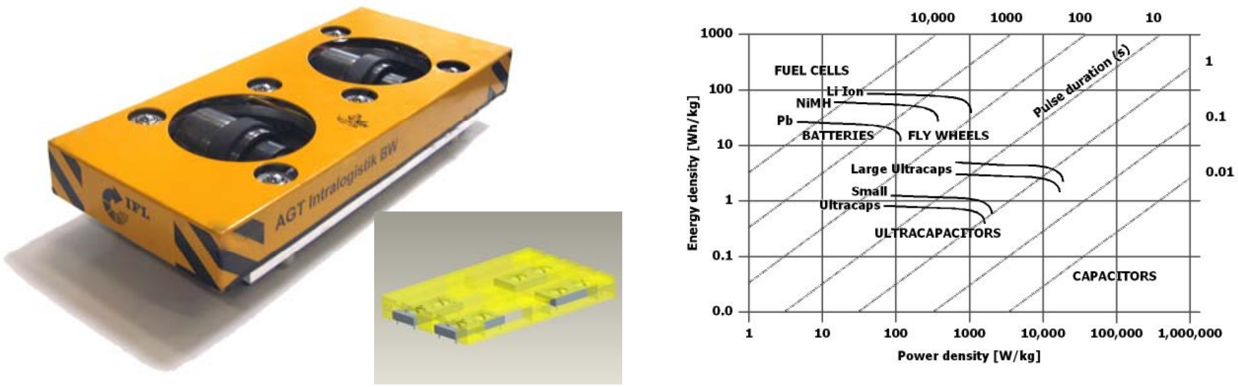


Figure 7 left: IFL's BInE (Basic INtralogistic Element), right: energy density of energy storage systems, source: [5]

Considering energy supply the state-of-the-art provides on the one hand powerful energy transmission systems, e.g. inductive power transmission systems and on the other hand a variety of energy storage systems with a high energy density, a high cycle durability (figure 7, right) and different charging and discharging characteristics. Even power generation by fuel cells could be apart of a future energy supply. With an intelligent power management, including a mix of power transmission, energy storage systems, power generation and an intelligent drive control the energy supply of a basic element can be realized. The power supply of the BInE (figure 7) for example with 2 rechargeable batteries 9.6V allows a total duty cycle time of 20..30min (depending on the acceleration rate).

To control several vehicles in a formation is state of the art and is topic in various conferences on robotics and/or automation. For example Ghabcheloo, Pascoal, Silvestre and Kaminer [6] found an algorithm to keep vehicles in an imposed formation pattern. The regarded configuration is a parallel one.

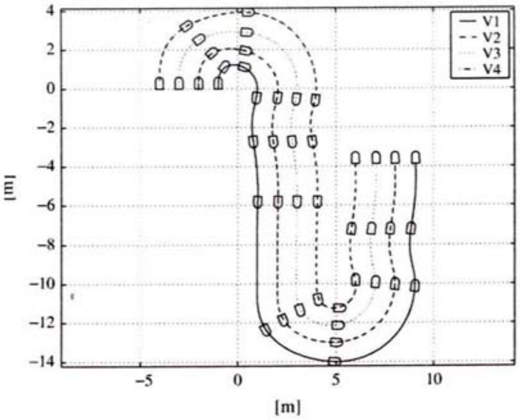


Figure 6: Coordinated path following, source: [6]

As shown in figure 6 with this type of formation, it is not possible to transport rectangular cargo because of the different longitudinal dilatation in various tracks. In order to handle the mentioned problems it is important to analyse different steering mechanisms regarding possible omnidirectional or even holonomic necessities concerning dynamic effects as drift or slip. Omnidirectional and holonomic robots are tested and used e.g. as soccer robots. Even a few human controlled industrial vehicles are realized. Our current research deals with the robustness of the steering mechanisms and the reliability of the odometric data of the available techniques. The odometric data is necessary to support motion control and navigation. The BInE allows omnidirectional travelling and due to its dimensions is able to lift and transport a Euro palette of 1000 kg in a compound of four vehicles (figure 7, middle).

Due to the fact that in industrial environments electro-magnetic technique can be used for navigation only in a restricted way, the focus in navigation lies on optical sensors. Rescue robots for example use laser scanners for the mapping of unknown areas and localise their position by using the current and the mapped sensor data (University of Freiburg, Germany). The robustness of the process in an unknown area is limited so far but considering the use of this process in a structured and known environment like a shop floor or a distribution centre perhaps in combination with landmarks could lead to a robust localization.

As far as communication is concerned the technical advance is obvious in WLAN, BlueTooth, ZigBee, …. Communication systems for industrial environment, a large number of communication partners and a large bandwidth at the same time make proprietary protocols necessary. A special kind of communication is possible via RFID-technology. In the analyzed assembly line RFID-technology is used to transfer an order for material immediately from the parts-supply-flow-rack to the picking area. An implementation of this process is realized with the SmartRack invented by the IFL, University of Karlsruhe which is shown in figure 8. With RFID-read-write systems in each shelf the SmartRack identifies every bin and its location in the rack. With the SmartRack e-Kanban and VMI-processes can be realized easily and quickly at low investment costs.

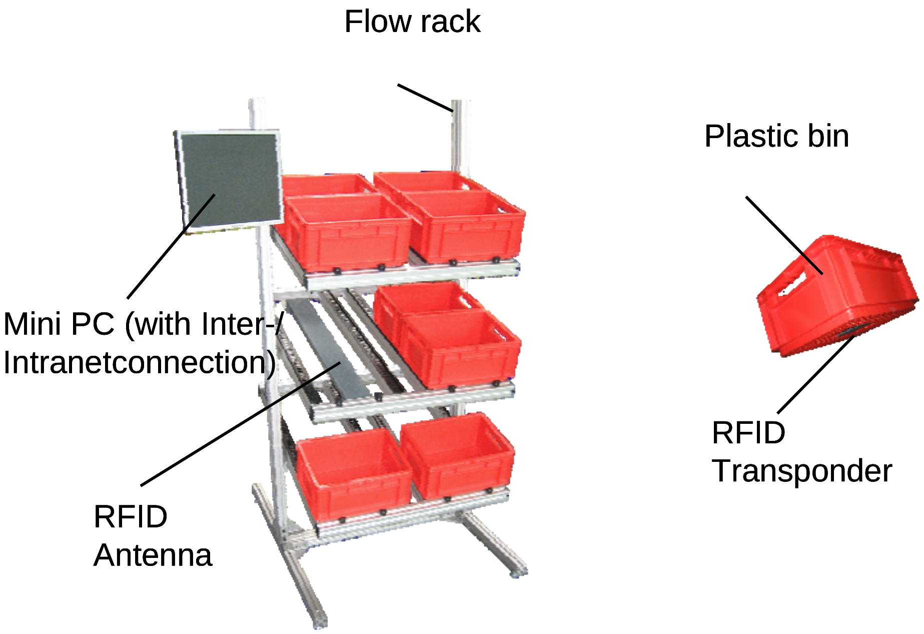


Figure 8: SmartRack

Decentralized autonomous controlled systems are a research field at the present. The investigations concern soccer robots (IIF, University of Freiburg) as well as logistic processes [7] and more. Additional to these activities we develop an extended layer model specialized on a system with the above architecture including the task management of basic elements and clusters. We hereby consider the limited amount of tasks in such a system and the state of research of swarm behaviour in nature. The layers reach from the system reference layer (in the current case: IFL's DCRM: Distribution Centre Reference Model) through information layers, a basic function layer,.. down to the physical layer.

Regarding the technological advances in the last ten years there are many technical solutions for the different technical issues. The great opportunity lies in the adaption and consolidation of the already existing solutions for the design of the basic elements for future material handling architecture. Large benefits can be achieved by using one technology for different functions, e.g. a laser scanner for localization, identification and safety. In a system of the introduced architecture economies of scale have an enormous effect on the system's investment costs. Especially the specification with a single basic element type requires a large amount of identical assemblies why it's predestined for serial production. Even in a system that consists of several specialized element types the total number of elements of the same type is high and even higher for assemblies if they have a modular design.

Open Issues and Outlook

Although many solutions for the different technical issues exist there is still considerable research effort necessary to realize a prototype of a system like the introduced one. Especially the autonomous cooperation and systems control which are mainly responsible for the system's robustness are quite far from an industrial application. The chance to deal with this discipline lies in the limited number of tasks and the more or less structured surrounding area of production and logistic systems compared to typical robot applications. To reach the state of a product for the basic element or even a serial production many of the nowadays technical solutions have to be improved. This implicates the miniaturizing of the devices (e.g. sensors) and to drop their costs of production.

In our opinion it is possible that first material handling systems of the future architecture will operate in a testing mode within the next 5 years.

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