Future Approaches to Meet Complexity Requirements in Material Handling Systems

Thorsten Schmidt
Full Professor
Technische Universität Dresden
Faculty of Mechanical Engineering

Frank Schulze
Research Assistant
Technische Universität Dresden
Faculty of Mechanical Engineering

Large material handling systems (MHS) face a continuous increase of system load, availability as well as flexibility issues. New approaches are born aiming at mastering those complexity issues, most of them represent paradigm changes in the way, how MHS are planned, designed, installed and operated. De-central control approaches gain through the availability of RFID-technology a new dimension of potential, also known as the Internet Of Things (IOT). Swarm like architectures may be an answer to the physical representation of IOT-paradigm in real world MHS. In order to achieve the desired goals, the future requirements, the potential of the new approaches and the thresholds to be passed have to be analysed thoroughly.

Keywords: *flexibility, mutability, small-scale, cognitive elements, traction drive technology, emergence, design methodolgy, coherence.*

1. INTRODUCTION

The design of any material flow system is everything else than simple. The vast majority of material flow systems has to cope with stochastic system loads and highly correlated processes as well as loads. Due to this, there are typically no analytical methods or tools available that could deliver a straight and unique solution to a given case. In addition it is expected that the ideal solution is stable and long-lasting, whereas the forecastability of future loads is decreasing continuously. First of all, there are two major issues to consider in any design task:

- Constraints and objectives in different companies are never the same. Even within a company the characteristics of different sites vary with respect to applied machinery, the number of regional customers, their specific requirements and the time-based linking of in- and outgoing material flows. In diverse companies in addition a set of additional criteria, such as clientele, integration into supply networks, the positioning within the retail channel have to be observed;
- On the market compete a plenty of suppliers that offer an enormous spectrum of system technologies. These have different advantages and disadvantages. Suppliers are beyond that keen on having a unique selling proposition (USP). Thus the applied systems are for good reasons not alike.

Hence, it can easily be concluded that in facility logistics there is no best solution, i.e. the ideal system for a certain type of problem does not exist. The design of complex MHS is by all means a project that involves detailed data analysis, conscious definition of objectives (jointly with the client), the generation of solution variants, their assessment, and finally the choice and refining of a preferred alternative. Depending on the type of problem, additional validation – quite often by means of discrete event simulation – may be necessary.

This entire process requires expert knowledge and is often done by specialized system planners. Well known and classical criteria in the design process of logistical systems are:

- minimization of costs (by means of e.g. maximal utilization of resources, inventory minimization),
- quality of service (order lead time, timeliness, error levels),
- flexibility (ability to cope with changing process parameters, such as order structure or article structure) and
- scalability (ability to grow with increasing system load).

All of these requirements are important but vary in relevance depending on the current economical, competitive, political, and perhaps even social situation.

The current economical crisis fosters the pursuit of a maximum level of flexibility. Especially, logistics service providers are trying to compensate a decline in system utilization by servicing alternative orders or clients. At this point the benefit of a system, that is able to process a wide spectrum of articles or customer orders with no substantial loss in efficiency, becomes obvious. Flexibility will thus obtain special attention in the following.

In addition, a decline in product life cycle is known for many years. A shortening of the innovation cycle accompanied by an increase of product diversity is the result. As a consequence, companies have to cope with new logistical requirements in ever shorter periods and have to adapt their material flow system to these requirements. This ability is defined as mutability, i.e. the ability to perform new (types of) transport tasks in least time possible.

Last but not least, in each design project one has to consider the trade-off between investment and operating

Received: October 2009, Accepted: November 2009
Correspondence to: Dr Thorsten Schmidt
TU Dresden, Inst. of Mater. Handling and Industrial Eng., 01062 Dresden, Germany
E-mail: thorsten.schmidt@tu-dresden.de

cost – a fundamental decision for any project, aside of the fulfilment of certain, indispensable requirements, such as meeting a peak throughput within limited time (i.e. sortation machinery) or handling of heavy parts (use of robots). Thus the required payback period influences to a large extent the design of the system, which again depends predominantly on the type of client company.

Especially in large and complex material flow systems a key cost driver is the design and implementation of the system control. More than any other area this field requires system specific rules and supplier-related knowledge. In addition, during lifetime of a system changes and extensions are inevitable. Every system adaptation typically requires repeatedly efforts (i.e. costs) for altering, testing and commissioning new strategies and algorithms within the system control. In order to reach a state of high stability (robustness), an in-depth analysis of the system behaviour under varying conditions and system parameters is crucial. In most cases this requires studies by means of discrete event system simulation.

In the classical case of a central control system (i.e. material flow controller) it can be assumed that all system states are well known to the control at any time. This centrality thus provides the possibility to apply various algorithms and strategies in order to optimize the system behaviour. In de-central structures this is not the case. However, in various approaches it is currently analysed whether this might nevertheless be the answer for mastering complexity. The key question is the additional benefit of highly mutable and robust systems. A question that is not easy to answer and that is a rather young constraint within the decision building process.

2. SELF ORGANISATION AND AUTONOMOUS CONTROL

Modern material handling systems have to master not only increasing flexibility requirements – complexity and dynamics of new systems rise constantly. Meanwhile, it becomes obvious that not only new transportation technology has to be engineered but also new control concepts. The traditional material flow control is centrally organized and hierarchically structured. For various reasons this concept encounters limits. Traditionally, it already accounts for a major part of the system generation costs, both in the control system design phase as well in the system ramp-up phase. Once successfully implemented, changes to the control system are (a) elaborate and costly, (b) quite often only possible by commissioning (and paying) the original system supplier, (c) risky (danger of unexpected downtimes) and thus (d) often an obstacle for the adaptability onto changed requirements and structures.

For this reason, the academic community intensifies its analyses on distributed, de-central decision taking in material flow. The objective is the generation of a reactive system behaviour (also known as *autonomous control*) that enables adaptability during runtime of a system with no external input.

The term *de-central control* specifies the change of the decision making towards the point of action. This first separation from the central philosophy is not quite new. In complex production systems e.g. field bus systems are in use for quite some time. These systems, primarily designed for reduction of wiring work in the assembly process, also support the integration of PLC (programmable logic controllers) for local control. Another reason for the extensive use of de-central control is the handling of time-critical processes, when communication bandwidth and reaction time do play an influential role. A de-central control for a conveyor and sortation system that has been realized by use of internet communication standards such as TCP/IP, HTTP, FTP and XML is described in [1].

However, the term *autonomous control* stands for a far-reaching change from the classical control philosophy. The key idea is the transfer of the knowledge of the object destination (and maybe desired object routing) to the transport object itself. Thus the decision making is partially shifted to the object or – more precisely – to the local decision point. In this context it is also referred to as the transfer of "intelligence" to the object. This change is significant and a clear cut with classical control philosophy. Therefore, it is also regarded as a paradigm change. There are various drivers to this shift, such as innovative developments in storage media and identification (in particular radio-frequency identification – RFID), energy transfer and energy accumulation (e.g. contactless energy transfer, battery technology, and super capacitors), information and communication technology (processing power, wireless communication), sensors (image processing) and miniaturization in general.

In production systems, in particular in automotive industry, RFID-technology has been already used for several years for the control of the production process. However, these applications are a closed loop (the control units stay within the system) and there are strictly limited functionalities. In other words: in these applications the RFID-systems just carry the production data, the decision is taken elsewhere.

The general application of RFID technology for the control of logistical systems (e.g. in-house material flow systems) place in contrast comprehensive requirements to such control logic. These applications are typically an open loop and various elements of a supply chain must work together.

The use of RFID and the promising developments made in this field will propagate the application of de-central control concepts for in-house material flows [2]. For this reason, it will be necessary to study the effects that these control concepts have on order-picking systems (OPS), which are, for example, a central link of distribution centres to the customer. In addition, order-picking systems are often very complex and, due to the large manpower requirements, represent a central expense factor.

The author analysed such an application in [3] by means of discrete event system simulation. The analysed system consists of 8 picking stations and 8 AS/RS, which supply the picking stations with article bins via a conveyor loop (Figure 1). The loop has a length of 104 m and a window control with a partition of 4 m for one bin each. Assuming at least one empty bin, the maximum load is 25 bins. The conveying speed is 1 m/s and determines the reaction speed of the conveyor system. There are several functions ensuring the supply and return of order bins of/from the loop. Each picking station has a bin infeed and bin output tracks for completed bins. At each station a maximum of 12 bins can be handled at the same time whereas an eventual increase of local way times is not considered because it is of no interest for this quantity.

Thus, in spite of the fact that there is no standard solution for material flow systems and it cannot be proved the investigated system is representative for a class of systems, it is believed the system reflects reality in sufficient detail.

The de-central control checks in front of each single picking station and for each arriving bin if (a) the article is required at the picking station and (b) at least one buffer slot is available at the infeed track. If the result is positive, the bin will be fed in. In the central control case various strategies were tested, the best performing strategy in this case was "RemainingCapacity", i.e. the remaining capacity of each of the infeed stations to the picking booths.

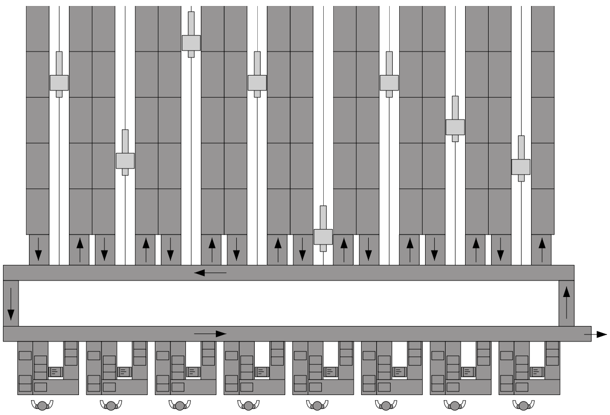


Figure 1. Layout of an analysed order picking system with part-to-picker and inversed picking [3]

The experiments have proven that de-central control strategies are suitable for the operation of part-to-picker OPS, where they control bin supply to a series of order picking stations that even operate according to the inverse picking principle, i.e. parallel picking at the order picking stations (Figure 2). The generated output in terms of system performance, measured in picks/hr or picker utilisation, is close to a central control strategy, subject to the condition that suitable improvement strategies are being utilised. In both cases different optimisation strategies were employed, the results consider the best performing result each.

Due to the similar performance results, in the future the decision of choosing a central or de-central control system for a certain application can be decided on basis of an investment comparison only.

3. MODULAR MATERIAL HANDLING EQUIPMENT

De-central control concepts and especially RFID-technology are first of all enablers for the successful implementation of the autonomous control philosophy in material flow. The vision is the autonomous (self-controlled) navigation of a logistical unit within a transportation network [4]. The de-central control of material flow components is based on autonomous elements and internet-based, real-time communication. The successful realisation of this young concept involves without doubt the definition of suitable and common standards for the universal application of self-control. Notwithstanding of all unsolved questions, by means of RFID a technology is available that provides the foundation for autonomous control.

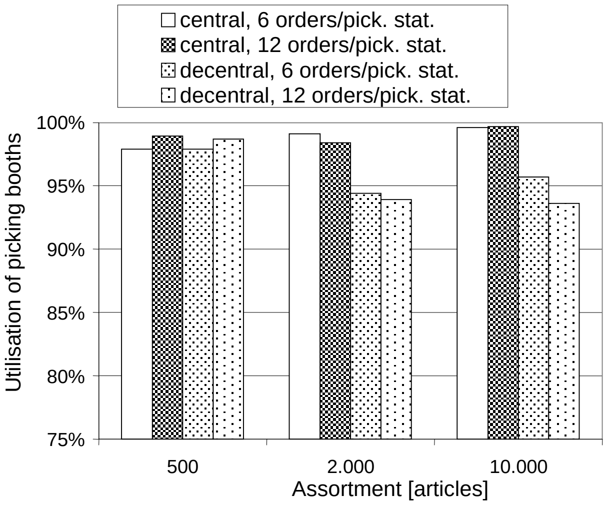


Figure 2. System performance of central and de-central control strategies in an order picking system with transport loop

A sustainable use of this potential requires not only advances in control technology but also in system and vehicle technology and other material handling equipment. This will be analysed in the following.

In order to realize the above mentioned objective of a highly mutable, on varying and widely unknown load states reacting material flow system, a thorough advancement of today's transport technology is vital. First activities within this area started from standard material handling equipment and focused onto a stepwise automatable system [5]. A transfer onto other logistical tasks was impossible or strictly limited.

In contrast, current developments follow new ideas and generate completely new concepts. A key idea of some of these approaches is the use of small and simple, "small-scale"-elements that can realise a transport task in combination only. Other developments focus on the forceful use of a multitude of vehicles.

Figure 5 shows the KARIS-concept (Small-scale autonomous redundant facility logistics system) of the "Arbeitsgemeinschaft Intralogistik Baden-Württemberg", Germany. The core of the system is the KARIS basic element ("BE", see Figure 3 and [6]). It owns a separate drive at the bottom including energy storage media and energy transfer devices and a conveyor element at the top. In the middle section the vehicle control and sensors are located.

Contrary to well-known AGV-technology this BE is not only designed for load transfer but also able to perform as a temporary conveyor line jointly with other individual BEs. In this case the BE itself is stationary, the delivery runs along the aligned BEs. Depending on the transport problem the element acts as a

- single transport unit,
- cluster transport unit (if the load overweighs the capacity of a single element), or
- temporary conveyor line.

This system is still in the development stage. The developers aim at finishing the control system of the single units on a laboratory level within 2009.

Figure 3. KARIS-basic element (500 mm × 500 mm × 400 mm) [6]

While in the former case or similar developments a series of functions (of the single vehicle) is still controlled by means of a joint logic unit (i.e. vehicle based, de-central control), the concept of Overmeyer et al. [7] defines the control ranges on the smallest element possible. The idea is the generation of a "cognitive logistical network", a combination of small cognitive modules. In this case the material handling functionality can be reached by interlinking of several modules only. The single module in this case is considerably smaller than the transport unit. Several modules are thus needed to carry and forward the transport unit. Each of the modules contains sensory and information processing components. These act as a base for a decision network within a decision matrix. The total system behaviour results from the local decision taking of its components. The general approach in the design of the modules in this case is to reach maximum flexibility of the single module, in order to end up with a minimal number of single elements for the design of the transport system. Such a sketch is shown in Figure 4.

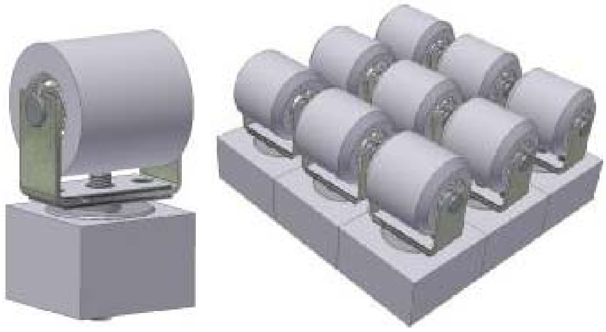


Figure 4. Concept study of a cognitive material flow system based on pivot rollers [7]

The solution "Mobile Fulfilment System" from Kiva Systems is a known application in industrial use which operates with a multitude of automated guided vehicles. Contrary to other known applications of AGV-technology this concept employs so many vehicles that a complete order picking system on Part-to-Picker basis runs by this transport system only. In this application the AGVs transport shelves to order picking booths. Since there is no fixed but a flexible arrangement of shelves, the shelves can be positioned depending on article picking frequency, size etc. This results in a high flexibility with regard to order structure and article behaviour. In order to achieve this (economically justified), a consistent push in the development obviously was inevitable (unit localisation, human safety). In opposite to the examples introduced before, the control operates in this case classical, i.e. centrally. In so far this system rather is an example for the efficiency of vehicle based material flow systems.

Along with the intensified development of small-scale transport units an old technical requirement of vehicle technology receives a new push: the traction drive technology. With the development especially of AGV technology various concepts were introduced in order to improve the vehicle manoeuvrability.

Up to now, industrially-used vehicles employ mainly linear drives, either as combination of two controlled and two rigid wheels or in form of a differential drive. The reason for this is predominantly the desired reduction of costly controls, drives and bearings. In addition, the steering of a controlled wheel while the vehicle is not moving itself (rotating on the spot) may create high punctual pressure and thus wear on wheel and floor.

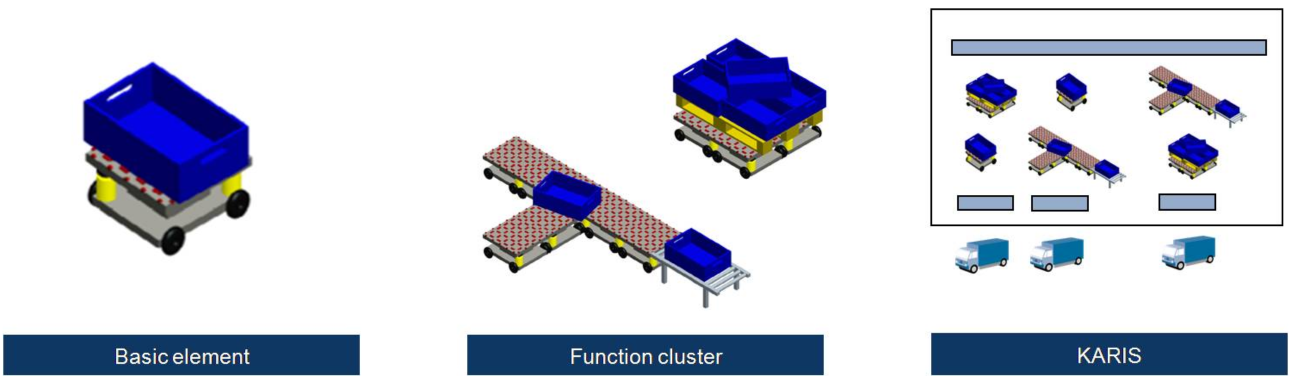


Figure 5. Structure of the KARIS system [6]

However, various disadvantages result from the limited manoeuvrability:

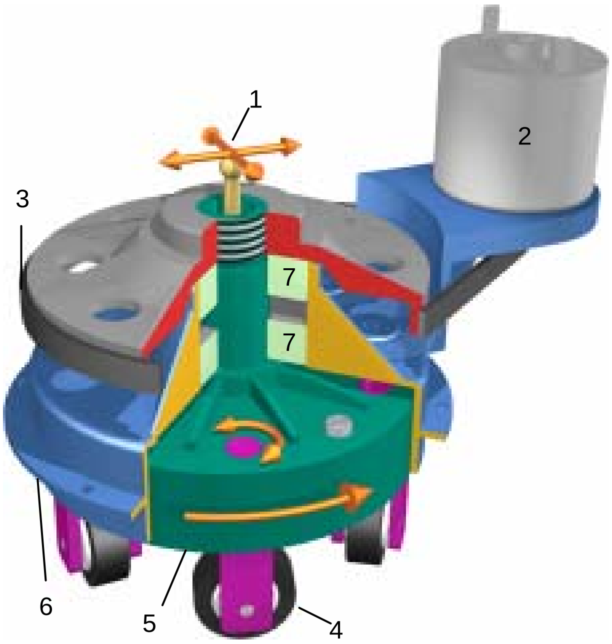
- no traversing of flight direction,
- increased space requirements in curves and at load transfers and
- limitations of layout flexibility.

These disadvantages inspired designers for years to search for highly movable but cost-efficient drive concepts. A well-known example for such an omnidirectional drive concept is the so-called Mecanum wheel, designed from Bengt Ilon, and named after the Swedish company he was at that time working for. The KARIS basic element shown in Figure 3 for example is equipped with a Mecanum wheel drive that owns a series of small, barrel-shaped rollers aligned on the circumference of a main wheel. The rollers typically have a 45-degree angle to the main wheel and point to the centre of the vehicle. Alternatively the axes of the rollers constitute a circle. By driving the four (main) wheels at different rpm any movement of the vehicle can be created.

The concept has been integrated into various vehicle designs and even in an experimental fork lift truck, but never managed to reach widespread use. Next to cost issues this is also due to the fact that the small wheels create a high load onto the floor and may create vibrations into the vehicle, depending on the quality and precision of the wheel fabrication. Unfortunately, due to the wheel concept, any tolerances highly correlate with each other, which boost the precision requirements. Last but not least unequal friction coefficients at the wheels in contact will create an unexpected movement that has to be compensated by additional control impulses. This increases yet the need for new drive concepts for small-scale vehicle that allow for both: omnidirectional movement at competitive cost.

A promising new concept in this area has recently been introduced by Fraunhofer IML, Dortmund. The so-called variable running gear (Fig. 6) has been inspired from maritime ship building. A series of small wheels rotate around a vertical axis. The small wheels itself are mounted onto a platform in a way that they are able to spin around their perpendicular axis (Figure 7). By deflecting a central point V, to whom the wheels always point perpendicularly to, the ensemble starts generating propulsion by rolling motion. Thus the driving speed is adjustable by the speed of the motors and the deflection of the drive. The running gear allows an excellent manoeuvrability resembling with an air cushion vehicle. Moreover, the running can be smoothly adjusted and offers thus a variable force and with constant drive rotation speed. Last but not least, the novel running gear features a particularly high load capacity since there is no sliding movement on the floor.

The next challenge is the enhancement of the vehicle safety means. From AGV-technology result well proved sensory means, such as tactile bumpers or laser scanners. Any form of tactile bumper however limits the vehicle's ability to couple closely which may become important when several vehicles are needed to transport one larger load (e.g. the KARIS concept, see above). On the other hand, laser scanner systems are far too expensive in order to equip a large fleet of vehicles. Thus R&D is focussing again on alternative concepts, such as image processing.



1 – Propulsion and direction control; 2 – Motor; 3 – Transmission; 4 – Wheels and suspension; 5 – Rotating wheel carrier with integrated shift levers; 6 – Carriage, mounted to vehicle; 7 – Bearings

Figure 6. Variable running gear [8]

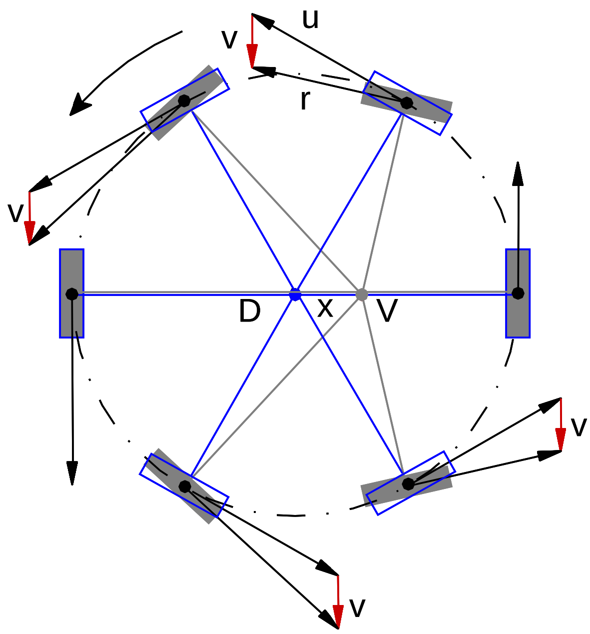


Figure 7. Kinematics of the variable running gear [8]

The travelling within a multitude of vehicles (swarm) also puts challenges to the vehicles' ability to handle obstacles. Certainly, a classical section control which just allows the presence of a single vehicle in a predefined section will not contribute to the idea of de-central decision taking of a multitude of elements (vehicles). In addition, the likelihood of unforeseen obstacles on the floor will rise with the degree of activity in the system. Presumably more lines of transport will be needed in parallel in order to cope with a required throughput. Real vehicle autonomy, i.e. the ability to detect alternative routes or paths if the planned route is not accessible, becomes a crucial. Whereas these requirements and research are not new, the initiatives mentioned before will fire the need and work on this field.

This all leads to the ultimate question in this area: the question how to handle a large fleet of independent entities. In recent literature the philosophy of the so-called *Internet of things* (IOT) has been addressed for the management of this task. However, the IOT appears in series of different meanings and lacks a clear definition [9]:

- Some define it as the effect that various things become able to communicate directly with the internet, also known as *ubiquitous computing*, i.e. "mini-computing", miniature-PCs that are tiny, cheap, energy-efficient, can be implemented in any part of every-day life. Different interfaces between computer technology, the human and appliances in general are being thought of;
- Closely related is the definition of the unique identification of objects via EPC (electronic product code). The EPC links the object with an internet webpage that holds various information on that product;
- Finally it is beeing thought of making use of the opportunity to alter the data carried in RFID-tags. Units (parcels, pallets, boxes) thus know not only who they are, but also where to go. Sooner or later they will most likely be able to communicate amoung each other [10].

On behalf of modular material handling equipment the third meaning of the IOT plays the major role. In the following, current issues on control of flows based on the IOT paradigm are further investigated.

4. OPEN ISSUES OF DE-CENTRAL CONTROL

4.1 Agent technology

Agent technology is supposed to be the No. 1 promising concept (and model for further discussion respectively) in order to implement de-central control structures. De-centrality can be understood in both ways, locally (e.g. distributed micro-controllers in a local control) or just conceptually (e.g. encapsulated software modules work inside a software system on a single PC).

A comprehensive study of Klein [11] regarding the state of art of agent technology shows that meanwhile agent based solutions push from scientific research widely into industrial applications. An example is the AMES platform (cf. [12]), a system developed at Technische Universität Dresden that is designed for the implementation of lean, real-time applications in automation technology.

Currently, there are numerous reports of promising solutions and approaches. Agent-based approaches worked so far quite well in problem instances with precisely defined partial tasks and limited information transfer between participating agents (cf. e.g. [11]). However, this lesson is already known from the concept of modularization.

Nonetheless, it should be kept in mind with respect to the theory of self-organisation – in fact agent systems are nothing else – that fundamental questions regarding the development of agent systems are not yet solved. This holds particularly for the so-called *emergence* of self-organising systems (cf. [13] pp. 30-32), for the *design methodology* of agent systems (cf. [14]), and for the so-called *coherence* of self-organising systems (cf. [15] Sec. 4.1):

- Up to now, the *emergent* behaviour of an agent system, i.e. the behaviour of the overall system resulting from a known behaviour of its individual agents (and thus its elements), can only be determined by simulation studies (e.g. [16]). And vice versa: In order to get a specific overall system behaviour the required functionality of single agents can only be derived by means of experiments;
- Consequently, only rough guidelines are available for the *design* of an agent system (such as DACS-methodology), a sound design methodology is missing. It thus predominately depends on the creativity and the skills of the designer, whether and how the transfer from the system specification into a functioning agent design with desired properties works;
- Finally, the question whether or not agents are typically able to develop a *coherent* behaviour, i.e. to adjust their potentially diverging interests towards a common goal (the control objective), is open. Conflicts among agents will result from limited resources as well as from restricted knowledge due to de-centrality. It is believed, that global coherence can be achieved by negotiations.

This first of all is not really surprising. It has to be pointed out, that control tasks are typically quite challenging. A simple solution to a highly complex problem is naturally somewhat unlikely.

Among the wealth of publications about agent technology there are only a few which describe approaches to "Dynamical control in large-scale [!] material handling systems", as Hallenborg and Demazeau [17] do for baggage handling systems. While the paper generally proves the feasibility of a multi-agent design, it still mentions fundamental problems, like "extensive message transport" (i.e. communication overhead). In this particular example co-ordination among agents is given precedence to negotiation, which is justified by references to certain system characteristics – but which is probably due to difficulties in finding a balanced design of negotiating agents as well. This conforms to experiences, which the authors of this paper gained in similar approaches to agent based control of baggage handling systems.

When looking for analogies from similar problems in other areas, it might be self-evident to analyse the methodologies in (national) economics science. Quite typical in economics, markets are places where limited resources and conflicting interests are balanced. The task is here to develop strategies to find alignments of these interests (cf. [18]). Surprisingly, economists do commit that functioning of markets and the development of equilibrium prices cannot be completely described – whereas engineers claim to design functioning markets by means of multi-agent systems. In fact, both address the same (actually unresolved) issue.

Driven by economic globalization and the rapid development of electronic business, new research arises from the field of agent-based computational economics such as *market based control* (cf. [19,20]), where experts from multi-agent systems, economic theory, evolutionary computation, and adaptive systems join to develop an automated interaction mechanism design for the control of complex, distributed computer-based systems. This approach is ambitious and it offers promising chances for the development of new control concepts for logistics systems, too.

4.2 Robustness vs. optimality?

Without a doubt, the key driver for the development of self-controlled systems based on a de-central approach is the increase of system robustness.

This however (might) lead to a disadvantage in the striving for a simultaneous optimization of the overall system (besides an increase in the local communication traffic). It is obvious that a de-central control with a limited information range cannot be better (or more precisely: more efficient) as a central control that has the entire system in view and owns all information on system states.

First of all, currently it cannot even be estimated whether this is at all regarded as a real disadvantage in industrial applications. In contrast to academic approaches, industrial applications regularly rank robustness higher than optimality.

Secondly, if frequent changes and alterations to the system are taken into account, the "optimal" behaviour of a central control may quickly become unstable. The question here is rather the average performance of the control philosophies under varying constraints.

Thirdly, most control systems operate in highly dynamic environments which constantly receive new jobs while processing older ones. In a strict sense, the control (i.e. optimization) problem then had to be reformulated upon arrival of each new job. Such a technique is called on-line optimization and is actually practised just occasionally. Rather, whole batches of jobs are handled by so-called off-line optimization algorithms which inevitably yield suboptimal results. Under such conditions, de-central algorithms, which operate on a local basis with a restricted time horizon, could perhaps perform better.

Finally, research indicates that de-central control strategies perform reasonably well (see Sec. 2, Figure 2, and [3]). However, the systems analysed so far are rather small in size and complexity.

5. CONCLUSION

This contribution tries to analyse upcoming requirements to the design of material handling systems. For various reasons a push towards de-centrally controlled systems is expected. A further potential is anticipated from advanced vehicle systems based on AGV system technology. These approaches mainly promise an increase of system robustness and system mutability.

In order to achieve this objective, collaborative efforts have to be undertaken that reach from the mechanical design to the control philosophy of large scale control systems.

Emerging vehicle concepts already influence this development and offer new solutions for traction drive concepts and system integration. Further efforts concentrate on efficient drive technology, energy storage and sensory means. The control of de-central systems require new paradigms as well. The most promising approach is being provided by multi-agent technology. Even through the functionality has been proven in singular cases based on simulation studies, a general design methodology is still missing. In particular questions of emergence and coherence of de-central system have to get solved. In conjunction with the system technology this represents the key goal in order to reach the desired robustness and mutability.

REFERENCES

[1] ten Hompel, M., Libert, S. and Sondhof, U.: Distributed control nodes for material flow system controls on the example of unit load conveyor and sorter facilities, Logistics Journal, No. 2, pp. 1-8, 2006.

[2] ten Hompel, M. and Lange, V. (Eds.): *RFID 2004: Logistiktrends für Industrie und Handel*, Praxiswissen, Dortmund, 2004.

[3] Schmidt, T. and Follert, G.: Analysis of decentral order-picking control concepts, in: *Proceedings of the International Conference on Dynamics in Logistics*, 28-30.08.2007, Bremen, Germany, pp. 457-464.

[4] Scholz-Reiter, B., Windt, K. and Freitag, M.: Autonomous logistic processes – new demands and first approaches, in: *Proceedings of the 37th CIRP International Seminar on Manufacturing Systems*, 19-21.05.2004, Budapest, Hungary, pp. 357-362.

[5] Wilke, M.: Control concept for autonomous changeable material flow systems, Logistics Journal, No. 1, pp. 1-6, 2008.

[6] Hippenmeyer, H., Furmans, K., Stoll, T. and Schönung, F.: KARIS – dezentral gesteuert, Hebezeuge Fördermittel, Vol. 49, No. 6, pp. 304-306, 2009.

[7] Overmeyer, L., Heiserich, G., Falkenberg, S. and Jungk, A.: Automatische konfiguration und optimierung von materialflusssystemen durch kognitive logistikmodule, in: *VDI-Berichte 2066, 18. Deutscher Materialfluss-Kongress*, VDI-Verlag, Düsseldorf, pp. 197-208, 2009.

[8] Fraunhofer IML, http://www.variabler-fahrantrieb.de/index_en.html

[9] Bullinger, H.-J. and ten Hompel, M. (Eds.): *Internet der Dinge*, Springer, Berlin Heidelberg, 2007.

[10] Trautmann, A.: Mulitagentensysteme im internet der dinge – konzepte und realisierung, in: Bullinger, H.-J. and ten Hompel, M. (Eds.): *Internet der Dinge*, Springer, Berlin, pp. 281-294, 2007.

[11] Klein, N.: *Multiagentensysteme: Theoretische Grundlagen und Einsatz zur dezentralen Steuerung automatisierter Materialflußsysteme*, VDM, Saarbrücken, 2008.

[12] Theiss, S., Vasyutynskyy, V. and Kabitzsch, K.: AMES – A resource-efficient platform for industrial agents, in: *Proceedings of the 7th IEEE International Workshop on Factory Communication Systems*, 21-23.05.2008, Dresden, Germany, pp. 405-413.

[13] Luck, M., McBurney, P., Shehory, O. and Willmott, S.: *Agent Technology: Computing as Interaction – A Roadmap for Agent Based Computing*, AgentLink III and University of Southampton , 2005.

[14] Klügl, F.: Multiagentensimulation, Informatik-Spektrum, Vol. 29, No. 6, pp. 412-415, 2006.

[15] Davis, R. and Smith, R.G.: Negotiation as a metaphor for distributed problem solving, Artificial Intelligence, Vol. 20, No. 1, pp. 63-109, 1983.

[16] Daniluk, D. and Trautmann, A.: Hardwarenahe emulation des multishuttle für ein multiagenten-basiertes steuerungssystem durch automod und HLA, in: *Proceedings oh the 12th ASIM Conference Simulation in Production and Logistics*, 26-27.09.2006, Kassel, Germany, pp. 551-560.

[17] Hallenborg, K. and Demazeau, Y.: Dynamical control in large-scale material handling systems through agent technology, in: *Proceedings of the IEEE/WIC/ACM International Conference on Intelligent Agent Technology*, 18-22.12.2006, Hong Kong, China, pp. 637-645.

[18] Eymann, T.: *AVALANCHE – Ein agentenbasierter dezentraler Koordinationsmechanismus für elektronische Märkte*, PhD thesis, Faculty of Economics and Behavioral Sciences, Universität Freiburg, Freiburg, 2000.

[19] Petric, A., Podobnik, V., Grguric, A. and Zemljic, M.: Designing an effective e-market: An overview of the CAT agent, Ketter, W., Rogers, A., Sadeh, N. and Walsh, W. (Eds.): *Proceedings of the AAAI-08 Workshop on Trading Agent Design and Analysis (TADA-08)*, 14.07.2008, Chicago, USA, pp. 1-4.

[20] Cai, K., Gerding, E., McBurney, P., Niu, J., Parsons, S. and Phelps, S.: *Overview of CAT: A Market Design Competition, Version 2.0*, Technical Report ULCS-09-005, Department of Computer Science, University of Liverpool, Liverpool, 2009.

БУДУЋНОСТ ПРИСТУПА ЗА ЗАДОВОЉЕЊЕ СЛОЖЕНИХ ЗАХТЕВА ТРАНСПОРТНИХ СИСТЕМА

Торстен Шмит, Франк Шулце

Велики транспортни системи се суочавају са сталним порастом оптерећења система, расположивости, као и проблемима флексибилности. Нови приступи су настали у циљу овладавања сложеним проблемима, а већина од њих представљају промене парадигме у начину како су транспортни системи планирани, пројектовани, инсталирани и како функционишу. Децентрализовани приступи управљања кроз доступност РФИД технологије дају нову димензију могућностима, такође познати и као Интернет Ствари. Архитектуре у облику роја могу да буде одговор на физичко представљање парадигме Интернета Ствари у реалном транспортном систему. У циљу постизања жељених циљева за будуће потребе, морају да се детаљно анализирају могућности усвајања нових приступа и граница.