Fast Deployable Autonomous Systems for Order Picking
How Small and Medium Size Enterprises Can Benefit from the Automation of the Picking Process

Marco Bonini, Augusto Urru and Wolfgang Echelmeyer
Forschungszentrum Logistik, Reutlingen University, Alteburgstrasse 150, Reutlingen, Germany

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Abstract: The paper focuses on a recently introduced paradigm for the logistic process of picking, with respect to the man-to-goods and goods-to-man concept: the robot-to-goods. First the task and system architecture of the fast deployable autonomous commissioning system are described, then the economic efficiency of the system is analysed in a real business case scenario using a simplified method, which is explained and discussed. The clearly positive Net Present Value of the investment and the short Payback Period obtained in the business case prove how the robot-to-goods paradigm for the commissioning process, implemented through the automation of the forklift platform, is economically attractive for small and medium size enterprises.

1 INTRODUCTION

The main logistic processes in which automation through robotic still has a great potential are three: (1) loading and unloading of unit loads, (2) palletizing and de-palletizing and (3) commissioning (or picking). Flexibility is the first challenge, because far too often application scenarios in logistics are unconstrained and dynamic. High performances and reliability are also required in order to make investments sustainable. Technologies for each of the three aforementioned logistic processes are available, but either they are partially incomplete or they don't properly fulfil each of the three criteria: flexibility, performance and cost (Bonini et al., 2015). For the (1) container loading and unloading process (Bortfeld and Wäscher, 2012) the only fully autonomous industrial solution available is the Parcel Robot (robotics logistics solutions). Other available technologies like the Automatic Truck Unloader (Wynright), the RobLog Industrial Demonstrator (RobLog Consortium), and the PIQR1 (TEUN) are either prototypes or only at an early stage of the development process.

For the (2) palletizing and de-palletizing process (Bischoff et al., 1995) the complexity level of the problem increases with the heterogeneity and lack of standardization of the items. The more the items are heterogeneous the more complex is the algorithm that calculates the pattern of each layer of the pallet (Wäscher et al., 2007). Not only the pallet needs to be stable, but also efficiently loaded (Terno et al., 1997), minimizing the free space between different items and different pallet layers (Kocjan and Holmström, 2008). Industrial solutions for sensors and actuators aiming at overcoming the needs of flexibility are available and mainly focused on the recognition and picking of non-identical items (RSW, Kuka Robotics, Qubiqa, Grenzebach Automation and Fimec Technologies).

For the process of (3) commissioning the answer of automation has been the transformation of man-to-goods systems in goods-to-man systems (Hamberg and Verriet, 2012). The most popular systems available are developed by Kiva, Autostore and Magazino. The first two follow the goods-to-man paradigm, the last one, still at conceptual and prototype stage, the robot-to-goods process. All of these systems however require high standardization of items and research is currently focusing on solving the problem of flexibility. Recently demonstrators from the best universities in the world were tested within the Amazon picking challenge held at the ICRA 2015 (Amazon) under the following constraints: the shelves were prototypical pods from Kiva Systems, and the robot (picker) had to be fully autonomous. Therefore the scenario was

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still not industrial, but sort of simplified. Besides the easy task of handling cuboids goods, some other tasks were included in the challenge: grasping of easy to damage goods (Oreo cookies, soft cover books) and objects hard to perceive with traditional vision systems and algorithm (Wurman, 2015). The transformation of a man-to-good system in goods-to-man is however not always possible and even when it is, it comes with large impact on the existing layout and with considerable investments.

Small and Medium size Enterprises (SMEs) seeking cost effectiveness of the commissioning process through automation are mostly based on the man-to-good paradigm; a complete re-design of both process and layout would result in a slow return of investment, increasing the risk.

This paper is focussed on the recently introduced robot-to-goods paradigm (Huanga, 2015) with respect to the traditional man-to-goods and goods-to-man concepts. First the task and architecture of the fast deployable autonomous commissioning system are described, then the economic efficiency of the system is analysed in a real business case scenario. As a result the automation of the forklift platform for the commissioning process is proved to be economically attractive for SMEs.

2 TASK AND SYSTEM ARCHITECTURE

In the following the task of the fast deployable autonomous system for warehouse commissioning automation is described, the challenges are explained and its potential architecture is outlined.

2.1 Navigation and Fast Deployment

The fast deployable autonomous system for warehouse commissioning automation is based on the hardware platform such as the EK-X, vertical order picker from Still GmbH (Figure 1.a). This forklift vehicle is currently used to navigate in high rack warehouses enabling the safe picking of items up to 12m high, all operations being manually accomplished by an on-board operator (Figure 1, b). The first challenge consists of transforming the EK-X into an Automated Guided Vehicle (AGV), using Simultaneous Localization and Mapping (SLaM) methods, which are not based on localization infrastructure (markers, reflectors etc.), while still being capable of providing highly accurate pose estimates in a changing dynamic environment. Being infrastructure-independent (no markers or reflectors, no a priori knowledge of the warehouse) these SLaM methods are essential for the system to be quickly deployable, reducing the barrier to the test and to the set-up investment.

2.2 Picking and Mixed Palletizing

Advanced navigation technologies are however not enough for accomplishing the commissioning task: when the location of the target item has been reached, identifying the exact position of the item, grasping it and placing it safely onto a pallet are all challenges that still need to be tackled. These operations involve robots abilities such as object recognition, motion, manipulation and decisional autonomy.

Figure 1: overview of the starting hardware platform and the current manual picking process.

The fast deployable autonomous system for warehouse commissioning automation is set to operate in a high rack warehouse where pallets with homogeneous parcels (same shape and dimensions) are stored: before the in-feed in the high rack stock these pallets are often wrapped in plastic foil for safety and security reasons. After the AGV has navigated to the right location, (1) the manipulator has to be positioned at the right height for picking the desired parcel(s), (2) the plastic wrapping surrounding the pallet (if any) and its parcels must be cut (in case the pallet is still complete, using principles like those implemented in the DefoCube, by LMS Development Concept, the Robotic Unwrapper, by BW Container System, or the MSK Defotech, by MSK Covertech Group) and finally (3) the right number of parcels has to be picked and placed in the commissioning pallet on the AGV (placed on the adjustable front forklift of the EK-X, moving at the same height as the manipulator) in a way that the resulting parcel staple is space-optimized and stable. An overview of the commissioning scenario, including a sketch of the hardware, is shown in Figure 2: overview of the industrial demonstrator application scenario., together with the section of the mobile robot's workspace needed in each corridor of the warehouse.

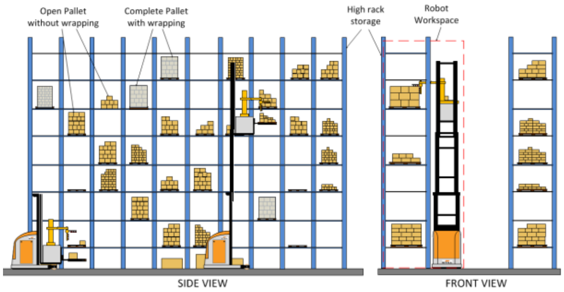

Figure 2: overview of the industrial demonstrator application scenario.

2.3 IT Warehouse Integration

Two additional challenges need to be tackled after the picking process and in-between two picks respectively: (1) the interface with the Warehouse Management System (WMS) and (2) the Collaborative Mission Planning and Fleet Management. The stock in warehouses is managed by the WMS and an interface with this module is necessary in order to automate the task of forwarding to the mission planner the commissioning list and to update the stock status. However, items in the commissioning list must be prioritized according to specific rules, such as: pallet stability, route optimization, traffic, and possible synergies among AGVs in the picking strategies. The mission planner and fleet manager module will satisfy these requirements through compromises between centralized and decentralized decisions.

3 EVALUATION OF ECONOMIC IMPACT

In this section the potential economic impact of the autonomous picking system previously introduced is quantified and evaluated in a potential business case, in order to give a hint of the economic benefits a SME could have by investing in an in such a system. The study case considers facts and figures provided by a SME (Small Medium Enterprise), located in Hohenstein-Ernstthal (Saxony, Germany), dealing with transport and in-house logistics. First, data concerning the current manual process are collected and analysed, then possible characteristics and performances of the future fully automated warehouse are discussed and a comparison between the current and future scenarios is carried out. Finally the estimation of the differential cash flows enables the calculation of the Net Present Value (NPV) function which is a key factor in investment decision-making.

3.1 Evaluation Scenario

Nowadays the company on which the analysis is based is active 250 days per year and is operating two (2) shifts per day. Each shift, seven (7) manually operated vehicles similar to the EK-X, with respective operators on board, are driven through the shelves of the warehouse in order to compile the orders. The number of picks per year is 500.000 on average and each order includes averagely 16 items. From this data the performance of the current overall picking process can be calculated.

Considering the same application, with the implementation of the autonomous picking system, the following reasonable hypotheses can be formulated:

- The on board operator is replaced by a robot mounted on the AGV
- The fleet of 7 autonomous vehicles is able to work two (2) shifts without any additional cost (only some minor direct cost for additional energy, not comparable to the additional cost of additional workers for additional shifts).
- The automated commissioning task will be performed in comparable time to the manual one (maybe the picking operation will be slower than the manual one, but the navigation time can be improved due to collaborative picking strategies).
- The only cost considered for the new vehicle is arising from the additional modules needed in order for the vehicle to be autonomous in the navigation and in the picking, such as: vision system, specific gripper and manipulator and other necessary hardware modifications from the existing forklift hardware. All these costs are in this business case estimated for a total amount of 110.000€. In the warehouse, seven (7) EK-X or similar would already be in use for the manual process. Thus, no additional cost for buying forklift equipment has been considered.
- The additional costs for service, support and maintenance are not deemed to be relevant for a first simplified analysis and therefore are neglected in the following.

- The cost of the autonomous fleet supervisor needed for managing exceptions is evened out with the cost of the supervisor and warehouse manager of the current manual process, which is no longer needed.
- The power consumption of the new autonomous system will be higher than the one in the currently deployed devices, but the difference is for the first analysis considered to be negligible.
- Since the system will be rapidly deployable it is assumed that the additional costs for the system set-up and installation at the user's site are negligible or included in the 110.000€.

The following summary table shows the parameters, grouped by time, operation, performance and cost, considering first the current, then the future commissioning process (after the implementation of the autonomous system).

Table 1: Parameters for the current and the future commissioning process.

	Parameter	***Current system***	***Autonomous system***
Time	Working days per year	250	250
	Shift per day	2	2
Operation	# of employees per shift	7	**0**
	# of picks per year	500.000	500.000
	# of item per order	16	16
Performance	Mean time fulfilling 1 order [min]	53,76	53,76
	Mean time per picking [min]	3,36	3,36
Cost	Cost of the operator per year (gross) [€]	28.105	**0**
	Cost for additional modules on 1 vehicle [€]	0	**110.000**

3.2 Investment Analysis

Implementing the autonomous system at the year 0, the company should invest an amount of 770.000 €, necessary for 7 autonomous vehicles. However from the moment the system is deployed and in action, the cost of the operators (7 by 2 shifts, so 14) ceases to exist, enabling constant savings for 393.470€ per year.

The cash flows estimation allows the calculation of the NPV, exploiting the following formula:

$$NPV(r, N) = -\left(\frac{Investment}{year\ 0}\right) + \sum_{i=1}^{N} \frac{NCF_i}{(1+r)^i} \quad (1)$$

Where:

- r is the interest rate, considered to be equal to 10% in this calculation;
- N is the service life of the autonomous system set to 10 years
- NCFi is the net cash flow at the year i of the life of the systems: this parameter describes the savings that the autonomous system enables every year in comparison to the current manual process.

This NPV approach considers the greater risk of the cash flows which are further in the future, thanks to the actualization factor (denominator), penalizing cash flows which lie further ahead (and therefore are not certain) and considering instead the certainty of investing in year 0 (this amount is not reduced by the actualization factor).

Table 2: Expected cash flows of the differential savings.

Year	Cash flow	NPV [€]
0	-770.000 €	-770.000 €
1	393.470 €	-412.300 €
2	393.470 €	-87.118 €
3	393.470 €	208.502 €
4	393.470 €	477.247 €
5	393.470 €	721.561 €
6	393.470 €	943.664 €
7	393.470 €	1.145.577 €
8	393.470 €	1.329.133 €
9	393.470 €	1.496.003 €
10	393.470 €	1.647.703 €

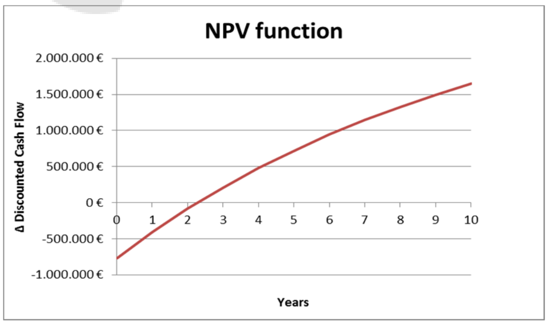

Figure 3: NPV Function.

3.3 Results

The result of the analysis highlights two points:

- The NPV at the end of the life of the system is positive (year 10, 1.647.703€), which generally is the first factor for a positive decision whether to invest;

- The NPV becomes positive in slightly more than 2 years, minimizing the risks linked to the uncertainty (namely the Discounted Payback Period), which is an additional factor for a positive decision of investment.

4 DISCUSSION

In this first rough analysis some possible synergies and factors that could increase the NPV and decrease the Payback Time have not been considered, such as:

- Possibility of exploiting the night shift and the week-end without additional costs, increasing the capacity;
- Thanks to the AGV fleet coordinator and mission planner, collaborative planning and picking techniques could be enabled. This directly impacts on shorter routes for AGVs and thus results in time savings and improvement of the overall performance of the system. In turn this could mean either that less vehicle are necessary or that the capacity can be increased. This would further reduce the payback time under 2 years;
- With the autonomous systems, the route and picking sequence are chosen for the pallet to be stable: this means that no additional time at the picking place must be spent by the system for moving parcels around in order to achieve the pallet stability. This can be translated in time saving with respect to the current manual process: currently, while picking, the operator needs to identify on the fly the most stable position for the parcels taking into account the overall stability and that there will be more items on the same pallet. Even though the result of a human operator compiling a mixed pallet will most likely be better in stability and volume optimization, the robot is able to pre-plan this, which avoids re-palletization that even the most experienced human operator needs to accomplish in order to reach a satisfactory result;
- The depreciation tax shield, not included in this model, will have a further positive impact on the NPV, further pushing towards a positive decision of investment.

In the presented business case, for the purpose of demonstrating its utility and convenience, the fast deployable autonomous system for order picking is considered as a product, hence with a technology readiness level (TRL) of 9, namely as an "actual system proven in operational environment" (European Commission). As a matter of fact, even if most of its sub-systems - such as the SLaM module or the feet management - have a high TRL (7 or more), the system as a whole has a current TRL of 2 ("technology concept formulated"), because its sub-systems have not yet been integrated, tested and optimized in their potential synergies.

The future work in this regard is twofold. First (1) step changes in TRL of the single modules need to be achieved; in particular the manipulator and the technology to cut the pallet's wrapping need to be optimized in order to be lightweight, since they are to be in operation at 10 meters height and suitable for the few cluttered workspace available between the shelves of the warehouse. Then (2) work needs to focus on the integration of each module, proofing the effectiveness and efficiency of the whole system. Only in this second phase it will be possible to assess open points concerning, for instance, the overall system positioning accuracy or the autonomy and efficiency of its power supply.

5 CONCLUSIONS

This paper shows how the robot-to-goods paradigm, implemented thanks to a fast deployable autonomous commissioning system, can enable savings for small and medium size logistic enterprises. First the task and system architecture have been described, then the economic efficiency of fast deployable autonomous commissioning systems has been analysed in a real business case scenario. The simplified method used for the business case analysis has been explained and discussed. The clearly positive Net Present Value of the investment and the short Payback Period, proved how the automation of the forklift platform for the commissioning process is economically attractive for SMEs.

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