HEAVY-LARGE RAW MATERIALS FEEDING IN LAYOUT-CONSTRAINED CONTINUOUS PRODUCTION SYSTEMS

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Abstract. This paper discusses several alternatives for automating the handling process of heavy-large loads from a raw material warehouse to a manufacturing department housing parallel continuous production lines in layout constrained facilities. For each alternative some criteria are given for preliminary sizing of the handling systems in order to allow a technical and economical comparison in an early decision stage. Additionally, the relative advantages and drawbacks of each alternative are discussed so that logistic managers and facility planners can make informed decision about the preferable choice in a given context.

Keywords: automation, material handling, continuous production lines

1. INTRODUCTION

In continuous production systems utilizing high speed automated machines, the final product is the outcome of a continuous process instead of an assembly of discrete parts. In contrast to assembly lines made of multiple stations, there are no discrete components to be supplied in totes, kits or containers to the stations but, rather, raw materials in bulk quantities are moved to the line in order to load and setup the machine before a production run. In continuous production lines that have to be fed with heavy-large raw materials, therefore, many problems arise from handling operations which, normally, involve many repeated moves such as unloading, store, pick, and transfer towards shop floor. Many industrial sectors and production processes share this kind of requirements, such as the sheet metal working industry, including coils production, and sheet coating, stamping, cutting, slitting, forming, pressing and punching lines for instance, or the pulp and paper industry, from blank paper reels production to manufacture of personal care items like sanitary napkins and baby diapers, or even the printing & graphics industry including magazines, books and newspapers printing. Other examples are metalworking of heavy cast items such as engine blocks or electric motors manufacturing, plastic film or metallized film production, textile industries, cables production etc., where large sized rolls, drums, reels and bobbins are moved between machines and warehouses.

Due to layout constraints, in the above factory environments material handling is usually carried out in a manual way, introducing labor, safety, and efficiency problems because handling automation is very difficult to apply and rarely utilized. In such production systems, in fact, a large number of different raw materials having non standard shapes, sizes and weights are used, such as rolls and bobbins of different height/diameter ratios or bags of flexible materials. Moreover, when multiple parallel lines are used, the lane width between adjoining lines can be very small (even less than 2 m) hampering vehicles movements. Therefore, manual material handling is utilized often employing fork lifts and hand carts. However, manual material handling is costly and creates problems in quality and service level as well as safety hazards to operators due to weight and size of unit loads. Commonly encountered problems are materials damage caused by unwanted contacts with obstacles or fall of the materials from the truck, delivery of wrong material, late delivery, etc. Other problem areas lie in the manual processing of materials information leading to misplacements in the storage area. All of those problems may also cause costly machine stock out and line stoppages. Furthermore, to rectify a wrong delivery requires additional material handling effort to bring back the wrong material and carry in the correct one.

In order to overcome such a limit a possible approach may be oriented towards introducing specific automation devices able to move heavy-large items respecting the layout constraints. In this way considerable improvements in
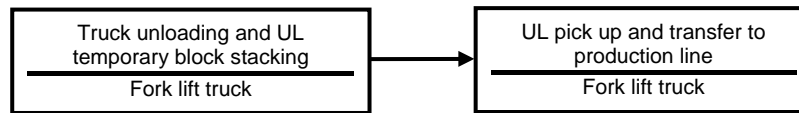
safety, efficiency, and labor cost may be pursued, also increasing quality and service levels. In this paper a number of alternative solutions for automated material handling in the above scenarios are proposed, and their merits and drawbacks are discussed from a cost and performance perspective. Considered alternatives integrate fork lifts and Automated Guided Vehicles (AGV) systems also utilizing different buffer storage racks architectures. The paper is organized as follows. At first the material handling alternatives are described, then general sizing criteria are given. Subsequently, some criteria to estimate the capital investment and operating costs are presented. This allows the user to make a preliminary sizing and economic comparison of each alternative in a specific context in order to evaluate its feasibility and select the best option. While in this work only a general methodological approach will be given, in future works each suggested solution will be analysed in detail and compared in selected scenarios. This will allow to show the practical applicability of the method also quantifying the relative advantages and drawbacks of each solution in realistic industrial applications.

2. DISCUSSION OF ALTERNATIVE MATERIAL HANDLING SYSTEMS

Material handling systems (MHS) are a critical component of manufacturing facilities as they implement the flow paths planned during facility layout between each department. MHS allow parts and material transportation between various stages of processing, being also responsible for ensuring the right product, location, condition, quantity and timing of materials delivery. Material handling processes include three primary activities: loading and unloading, movement to and from storage, and order filling (Askin and Standridge, 1993; Frazelle, 2002; Heragu, 1997; Mulcahy, 1998; Tompkins et al., 2003). Material handling, which is a non value adding activity, strongly affects production costs as 20% to 70% of a product's cost can be attributed to material handling. However, it supports the manufacturing process and is critical to attain the desired level of efficiency and effectiveness of the production system, contributing to the firm competitiveness and its overall logistic performances. In manufacturing systems scenarios characterized by a high intensity of material flows MHS represent often the main capacity limit (Askin and Standridge, 1993; Beamon, 1999; Heragu, 1997; Mulcahy, 1998; Tanchoco and Agee, 1981). MHS, therefore, may act as bottlenecks limiting the utilization of available productive capacity or hampering an increase of production volumes to meet a growing market demand. This is more likely to occur when the MHS is shared among several production lines. When designing the MHS, an equipment type must be specified for each material movement in order to better support the overall mission of the production facility. The choice must respect available budget constraints and minimize design and operational costs, still considering all relevant interaction and integration issues among the different kinds of resources utilized (Tanchoco and Agee, 1981). Many equipment alternatives are available to a MHS designer (Askin and Standridge, 1993; Heragu, 1997; Mulcahy, 1998). Considering the economic relevance of this issue a number of procedures for the selection of proper material handling equipment and their economic justification have been proposed in the literature. As an example, Park (1996), Welgama and Gibson (1995) and Fonseca et al. (2004) suggested the adoption of knowledge based expert systems. Chan et al. (2001) integrated expert system with analytical hierarchy process, while Kulak (2005) developed a fuzzy multi-attribute selection method. Standard linear programming approaches for optimal selection of material handling equipment can be found in textbooks (Askin and Standridge, 1993; Heragu, 1997; Sule, 2009). Finally, Usher et al. (2001) provided an economic justification framework for material handling equipment investment decisions. Nevertheless, in this paper, instead of utilizing a general purpose method, we adopt a bottom-up approach starting with peculiar constraints and requirements dictated by the specific manufacturing system under analysis, to derive alternative MHS options. Such options can be used as a starting point for logistic managers in charge of developing MHS automation projects in the examined application field.

In the considered facility scenario we assume a manufacturing department housing one or more continuous manufacturing lines fed by an adjoining raw materials warehouse. The warehouse receives materials from external suppliers in unit loads (UL) such as pallets, bobbins and so on, and stores them temporarily until the UL are moved to the production department to feed the line according to a production plan and the bill of materials of the products to be manufactured at any given time. Usually, each line is composed by a sequence of specific machines so that the line has multiple loading stations along its entire length where different materials have to be dropped off. Truck unloading is carried out manually resorting to fork lifts. Owing to the high rotation of materials feeding continuous lines a warehouse with storage racks is usually unnecessary and pallets are simply stacked in blocks on the floor to reduce space consumption. Fork lifts are then used to pick up UL from the stacks and move them to the drop off points along the lines. This is the standard material handling process assumed as a reference benchmark, and schematized in Figure 1 to represent the traditional non automated material handling solution (Alternative 0).

This reference solution is characterized by totally manually operated material handling, thus incurring in the following drawbacks, namely high cost owing to the large number of fork lift operators required, risk of materials damage owing to contacts with obstacles or fall of the materials from the truck, possibility of human error leading to misplacements in the storage area, delivery of wrong material, additional material handling effort to rectify a wrong deliveries, late delivery. This determines a reduction of service level which also causes costly machine stock out and line stoppages. Moreover, manual handling hazards due to weight and size of unit loads, threaten the health and safety of operators with related risk of injuries.

Truck unloading and UL temporary block stacking		UL pick up and transfer to production line
Fork lift truck	→	Fork lift truck

Figure 1. Handling process in Alternative 0.

When developing alternative material handling solutions the following issues should be considered as pertaining to the adopted vehicles and storage policy.

a) Materials transportation system from the storage area to the lines should be highly flexible and able to manage discontinuous flows towards multiple destinations over changing paths. This necessarily limits the choice to AGVs which are capable of autonomous guidance over variable paths and precise delivery to specific drop off points. Wrong or late deliveries are also eliminated thanks to unambiguous UL identification resorting to barcode or RFID systems and direct interfacing of the production control system with the AGV supervisory control system. Even safety and materials damage problems during transportation are greatly reduced by adopting AGVs. However, care should be taken in selecting the proper AGV type by checking that pick up and drop off maneuvers are allowed in the available space. Moreover, modifications to AGV picking and load holding equipment may be required to allow a single type of vehicle to manage different types of loads (i.e. both palletized loads, rolls and bobbins).

b) Automation of the truck unloading operation is currently unfeasible as AGV and other automated systems can not pick up UL within trucks interiors because their position is unknown and the storage space lacks the geometrical reference points needed to guide automated systems.

c) During the process of unloading incoming trucks, fork lift operators usually have not the time and practical possibility to identify each UL and selectively drop off each UL in a specified storage location known in advance, nor, in case of random storage, they can input in real time the drop off location into the warehouse management system. Moreover, space may not be available to hold the entire inventory within a rack so that block stacking becomes an obliged choices unless just in time policies are used for replenishing raw materials from external suppliers.

d) AGV and other automated systems can not pick up materials block stacked on the floor. In fact AGV require precisely and univocally positioned loads while the UL position is not precisely determined and UL in rows at different levels of the stacks are often not precisely aligned in order to improve stack stability. Moreover, automated picking requires the presence of a minimum space between UL, and sufficient aisle width to accomodate vehicles movement. This would make floor storage much more space consuming. Similarly, substituting block stacking with storage racks is often unfeasible for space reasons especially when a large variety of items has to be stored. In fact storage racks have a volumetric storage efficiency of about 50% respect about 85% of block stacking.

As a consequence, a number of constraints limit the generation of possible MHS alternatives.

- An AGV system is required for UL delivery to production lines (see item a)).

- Incoming truck unloading is to be carried out manually resorting to fork lifts (see item b)).

- Preliminary storage of incoming materials should take place on the floor adopting a block stacking policy (see item c)).

- A physical interface between the manual handling phase and the automated one is required. A storage area can serve this purpose by also acting as a decoupling point between inbound logistic activities and internal material handling which is slaved to production planning requirements.

- The storage buffer can take the form of storage racks or loading/unloading bays. However, materials location in this storage area should be precisely defined and accurately maintained for the UL to be accessible to AGV for picking (see item d)).

- A manual transfer between block stacking area and the mechanized storage area is required given that AGV can not pick from the stacks (see item d)).

2.1. Alternative 1

In Alternative 1 (Fig. 2 and 3) raw materials are unloaded from the supplier's truck and stored in a block stack resorting to fork lifts. Fork lift successively move unit loads from the stacks to AGV loading bays. AGV pick up loads from the bay and move them to production lines according to the production schedule. Loading bays simply are dedicated spaces on the warehouse floor acting as interface areas for AGV pick up. They can have one or more pallet

spaces thus acting as a buffer to decouple fork lifts activity from AGV, and are dedicated to each raw materials so that each time an AGV is asked to move a given UL to a line it can be automatically addressed to a predetermined picking location in a selective manner. Therefore, at least one bay per raw material code should be included. The bays can be even used for AGV discharge and fork lift pick up in case pallets or containers containing scrap or waste are returned back from the production lines for disposal. Obviously, bays can be equipped with special implements to hold in correct position the materials for easy pick up (for instance rolls should be placed in horizontal position).

From a technical stand point this is the simplest alternative. Moreover it has the advantage of minimizing handling moves as there is no need to further transfer to a subsequent buffer the material placed in the AGV loading bay as it acts as a buffer by itself. Capital investment is the lowest and there is no need for storage infrastructures. The only limitation comes from the extensive space utilization for the AGV loading bays which have to be at least as many as the different types of unit loads to be handled. The loading space within the bays is determined by the number of buffer loads to be stored during the supply lead time to avoid any disruption of manufacturing operations.
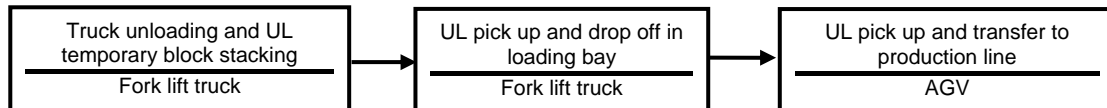
Truck unloading and UL temporary block stacking		UL pick up and drop off in loading bay		UL pick up and transfer to production line
Fork lift truck	→	Fork lift truck	→	AGV

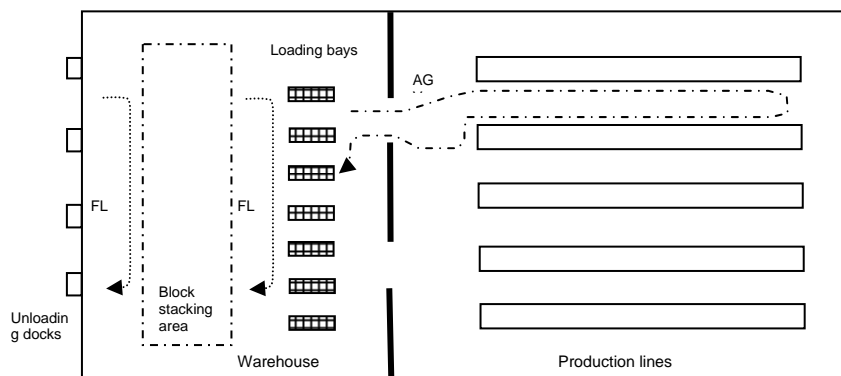**Figure 2. Handling process in Alternative 1.**

Figure 3. Sample layout of Alternative 1.

2.2. Alternative 2

Respect the previous one this Alternative replaces loading bays with a selective storage rack (Figures 4 and 5). Raw materials are unloaded from the supplier's truck and stored in a block stack resorting to fork lifts. Fork lift successively move unit loads from the stacks to the buffer storage rack placing them in predefined locations. AGV pick up loads from the storage rack and move them to production lines according to the production schedule. Please note that the storage rack is not intended to store all raw materials, which keep on being stored in bulk on the warehouse floor as block stacks, but only a limited amount of unit loads required to feed production lines for the duration of one or two shifts. Rack space is allocated according to the relative demand of each item. Scrap and waste materials returning from production lines are placed back in the storage rack and then picked by fork lifts for final disposal. A single depth rack can be used which can be accessed from both sides. One side is dedicated to material insertion by fork lift and the other for load removal by AGV. Please note that flow racks or multiple depth racks able to store more than one UL per storage bay are not suggested for this application if UL with irregular shapes, non standard dimensions or rolls have to be stored. In fact, materials could jam when flowing along the rack asking for human intervention, or they would require additional equipment, such as custom designed sleds, to guarantee a smooth flow. This would complicate the handling task, because the unit load should be separated from the sled after pick up and the sled returned back on the opposite slide of the rack before the load can be moved to destination.

Even the drop off of the load by the fork lift would be more complex as the sled should be taken off the rack, loaded and placed back in the rack, and in the case of rolls this would require a traditional fork lift to handle the loaded and unloaded sled and a truck equipped with special clamping grippers to hold and move the roll. The rack can have multiple vertical storage levels to reduce its length and floor space utilization, and the number of levels is limited by the building height and the extension height of fork lifts and AGV. Usually, racks up to 5 m tall can be serviced.
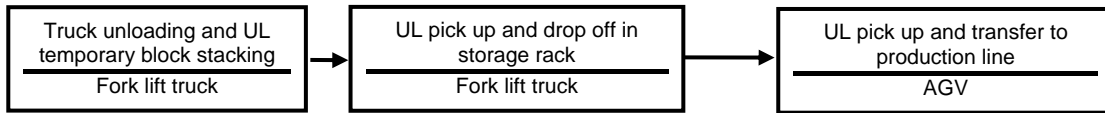
Truck unloading and UL temporary block stacking _____ Fork lift truck	→	UL pick up and drop off in storage rack _____ Fork lift truck	→	UL pick up and transfer to production line _____ AGV

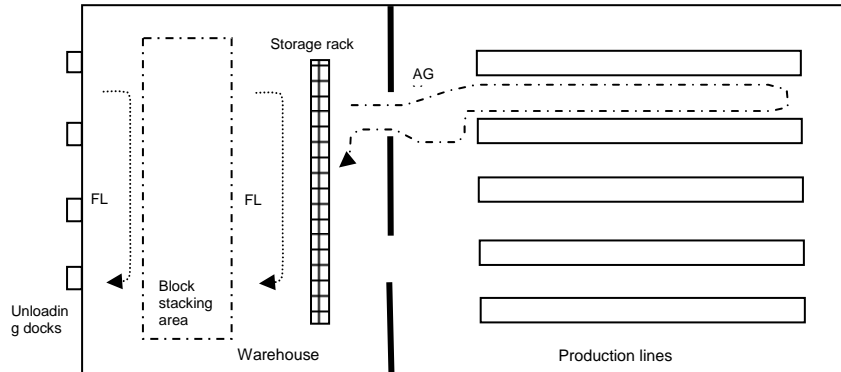**Figure 4. Handling process in Alternative 2.**

Figure 5. Sample layout of Alternative 2.

This alternative is less space consuming owing to the rack extension in elevation, but asks fork lift operators to drop off loads at high levels, which is an hazardous and delicate task. This task duration is even longer than the time required to drop off the load into a floor level bay. The number of required operators would increase and this may be against the stated cost saving goal.

2.3. Alternative 3

In Alternative 3 (Figs. 6 and 7) an automated system is added to drop off ULs in the buffer rack. Although a further operation is added, this avoids the fork lift operator to manually perform loads drop off in the rack bays. This is a time consuming and hazardous task, and if the operators is not precise in load positioning, the AGV can fail to correctly pick the load. A robot AS/RS system can be employed to perform this task. Therefore, raw materials are unloaded from the supplier's truck and stored in a block stack resorting to fork lifts. Fork lift successively move unit loads from the stacks to loading bays in proximity of the robot AS/RS system. The latter picks up loads and drops them off in the storage rack bays. AGV pick up loads from the storage rack bays and move them to production lines according to the production schedule. The fork lift operator is only asked to drop off the unit load on the floor in the AS/RS loading bay, and the rack loading process becomes faster.
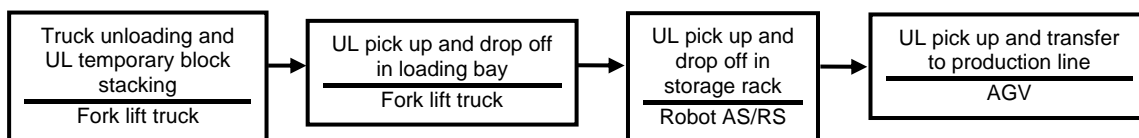
Truck unloading and UL temporary block stacking _____ Fork lift truck	→	UL pick up and drop off in loading bay _____ Fork lift truck	→	UL pick up and drop off in storage rack _____ Robot AS/RS	→	UL pick up and transfer to production line _____ AGV

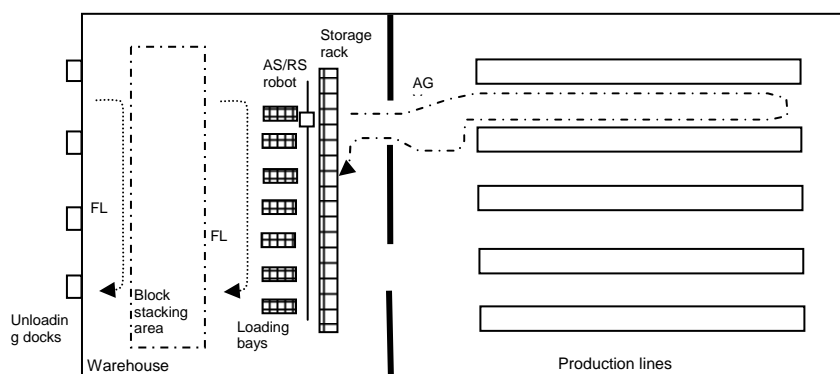**Figure 6. Handling process in Alternative 3.**

Figure 7. Sample layout of Alternative 3.

The main disadvantage of this alternative is the capital investment of the robot AS/RS system required to avoid operators to drop off loads in the rack bays. This cost could be in the 250.000-300.00 €range for typical applications and can be often greater than the cost of AGV in charge of executing the same task as assumed in Alternative 4. Even operating costs can be up to four times higher than a corresponding AGV system. This solution would be convenient, instead, when high rise racks (up to about 30 m) are used for intensive storage. Moreover, a further automated system is added and this increases system complexity and maintenance management. It should also be pointed out that any failure of the AS/RS robot would determine a production interruption as it is not practical to use stand by units as happens instead in AGV systems.

2.4. Alternative 4

This Alternative is depicted in Figs. 8 and 9 and differs from Alternative 3 in that the robot AS/RS is replaced by AGV. In this solution, therefore, AGVs are used to either load and unload the buffer rack, and the fork lift operators are only asked to unload the supplier truck, store the materials in block stack and then move loads from stacks to the loading bays from which AGV pick up loads to be placed in the rack. The entire handling cycle is as follows. Raw materials are unloaded from the supplier's truck and stored in a block stack resorting to fork lifts. Fork lift successively move unit loads from the stacks to AGV loading bays in proximity of the rack. AGVs pick up loads and drop them off in the storage rack bays. From the opposite side of the rack AGVs pick up loads from the storage bays and move them to production lines according to the production schedule. In case of waste materials coming from production lines, AGVs discharge them in the AGV loading bays and fork lifts pick up the unit loads for final disposal. This Alternative has the advantage of automated loads drop off in the storage rack bays and appears cheaper and more flexible than the previous ones. In fact, when an AGV has no load to insert in a rack bay it can be used to pick up loads from the rack and move them to production lines as there is no need for dedicated AGV for loading and unloading operations. However, respect the AS/RS solution it is more space consuming owing to vehicles manoeuvres requirements.
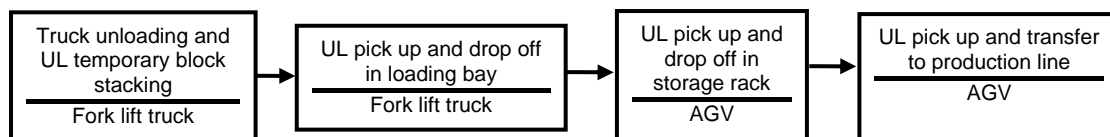

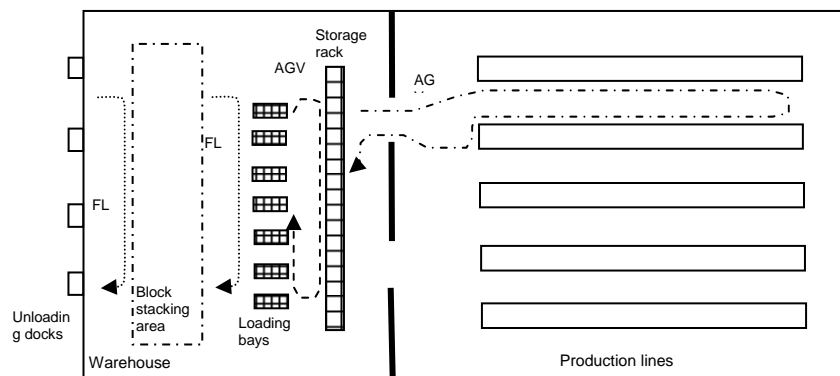**Figure 8. Handling process in Alternative 4.**

Figure 9. Sample layout of Alternative 4.

It should be pointed out that in the previous alternatives the option that fork lift operators engaged in truck unloading operations drop off the unit load directly in the buffer storage rack instead of in the floor stacks has not been taken into account. This would eliminate the intermediate step of moving unit loads from the stacks to the buffer rack. However, it has been also stated that this is not generally possible as it is not feasible to assign in real time a storage bay to a unit load while it is being picked up inside a truck, Moreover, the truck unloading phase would have an increased duration probably not compatible with drivers waiting time allowance and with loading docks occupation. Nevertheless, in case this kind of operation could be thought as feasible some new material handling alternatives arise. It should be pointed out as well that in the following alternatives the storage rack should have enough capacity to substitute the block stacking and hold the entire raw materials inventory. This could substantially increase the space occupation.

2.5. Alternative 5

In this case the fork lift operator directly moves the unit load from the truck bay to the buffer rack bay without an intermediate storage in a floor stack (Fig. 10). Then an AGV picks up the load and moves it to the production line.
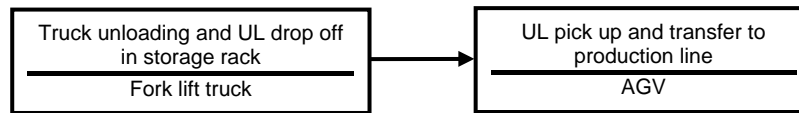
Figure 10. Handling process in Alternative 5.

2.6. Alternative 6 and 7

As a final remark it should be pointed out that if just in time warehouse replenishment policies are adopted, it can become feasible to hold the entire inventory in a rack, so that during trucks unloading the fork lift would pick up loads and drop off into an automated handling systems loading bays. The automated systems would pick incoming materials from the loading bays and drop them off in the rack bays, to subsequently pick it again to deliver loads to production lines. This would eliminate the intermediate transfer of unit loads from the floor stacks to the racks storage. This solution is included as Alternative 6 and 7. In alternative 6 the fork lift operator moves the unit load from the truck bay to the loading bay of an AS/RS robot loading the buffer rack (Fig. 11). Then an AGV picks up the load and moves it to the production line. Alternative 7 is the same except that the UL dropped off in the loading bay is picked up by an AGV for insertion in the buffer rack bays (Fig. 12).
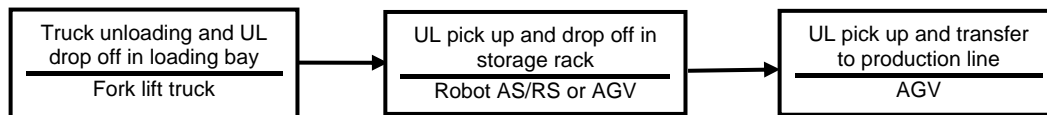

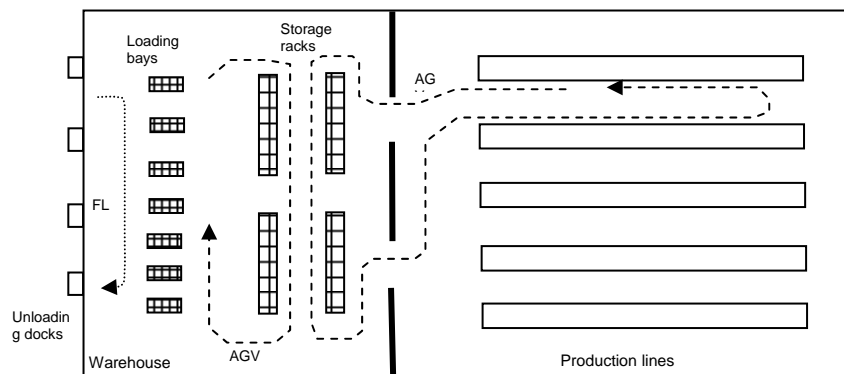**Figure 11. Handling process in Alternatives 6 (AS/RS) and 7 (AGV).**

Figure 12. Sample layout of Alternative 7 (AGV).

One can observe that the proposed solutions actually make the material handling process more complex than the original one (Alternative 0) due to the increased number of handling moves and the requirement for interfaces between manual and automated handling. One also notices that Alternative 7 appears to be the most rational, but it is subject to the possibility of replenishing the warehouse in a just in time manner in order to reduce the average inventory and make feasible a rack storage of the total raw materials inventory. Nevertheless, the switch to JIT flows management can be a long process and it can be even unfeasible in case of turbulent market environments.

Anyway, most of the proposed solutions are effective in reaching two of the top objectives of plant managers, i.e. reducing overall material handling costs thanks to a reduction in the number of operators involved, and obtaining greater safety and quality levels in operations. In fact, by adopting AGV to move loads from warehouse to production lines actually halves the work load of fork lift operators provided that the interposed buffer rack allows to decouple the rack replenishment operation (which is fairly steady) from the line supply operation (which is highly irregular as it follows the lot changes of the production plan). Moreover, most of the solutions could be considered as transition solutions towards a final solution such as Alternative 7.

3. RESOURCE SIZING CRITERIA

In order to perform an economic analysis, a preliminary resource sizing is required involving fork lifts trucks, AGV vehicles, robot AS/RS and rack storage space according to the considered alternative.

It is assumed that data regarding the number of UL moves per shift are given including either truck unloading moves TUM (UL moves/shift) and line supply moves LSM (UL moves/shift). On average the number of moves to replenish the buffer storage rack RSM (UL moves/shift) can be considered to equal to LSM.

In Alternatives 1 to 6 fork lifts should provide a total number of moves per shift NM = TUM + RSM, while in Alternative 7 it is only NM = TUM. We are neglecting additional moves to dispose scraps and waste brought back from manufacturing department, but those could be easily factored in.

For a fork lift the total cycle time per delivery per vehicle T_C is (Groover, 2000)

$$T_C = T_L + \frac{L_D}{V_C} + T_U + \frac{L_E}{V_E}$$
(1)

where T_L and T_U are the loading and unloading times respectively, L_D is the travelled distance between the loading and unloading station, L_E the distance the vehicle travels empty, V_C the loaded carrier velocity and V_E the empty carrier velocity. Specific values for the numerical parameters should be defined according to warehouse layout and handling task complexity. The number of required fork lift is

$$N_{FL} = \frac{NM \, T_C}{A \, T_f \, H \, E}$$
(2)

where A is the vehicle availability, T_f a traffic congestion factor, H the shift duration and E the worker efficiency.

The required number of AGV vehicles can be determined through Equation (1). However a more precise approach is given by (Caron, Marchet and Wegner, 1997) as follows. The overall time that AGV vehicles are busy is

$$T_N = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} \cdot \left[\frac{d_{ij}}{v} \cdot \frac{(1+b+c)}{A} + T_L + T_U \right]$$
(3)

where f_{ij} is the number of travels between stations i and j, n is the number of stations in the system, d_{ij} is the distance between stations i and j, v is the vehicle velocity, b is an inactivity coefficient accounting for non material handling trips and battery recharging stops (0.10<b<0.15), c is a traffic congestion blocking factor (0.45<c<0.65). The number of trips f_{ij} refers to trips from the storage rack to manufacturing lines, except in Alternatives 4 and 7 where trips to drop off loads in the storage rack are also included. Therefore, the required number of AGV vehicles is estimated as

$$N_{AGV} = \frac{T_N \, f_P}{H}$$
(4)

where f_P is a time inflating factor to account for peaks of transportation demand, ranging from 1.15 to 1.3 if the number of trips f_{ij} refers to average instead of peak values.

Sizing the storage rack requires defining the number of storage location to house unit loads. In industrial practice a rule of thumb could be that of storing as many UL in the buffer rack as are required by manufacturing lines during an entire shift, i.e. LSM locations provided that during loads transportation a single UL is moved per trip. If the storage rack has L levels, and each storage location has a length l and width w, then the shop floor space occupation of the pallet rack is

$$S_R = \frac{LSM \, l \, w}{L}$$
(5)

and the rack, provided that a single depth rack is used, would have a length $L_R = S_R/w$ and a height $H_R = L \, h$ where h is the storage location height.

As far as the robot AS/RS is concerned it would operate according to a single command cycle as only UL drop off in the storage rack is required given that AGV would be in charge of picking up ULs to be moved to production lines. In this case the average length of a cycle would be (Groover, 2000)

$$T_{CS} = Max \left\{ \frac{L_R}{v_y}, \frac{H_R}{v_z} \right\} + 2T_{PD}$$
(6)

where T_{PD} is the duration of a pick up or deposit operation, while v_y and v_z are respectively the velocity of the S/R machine along the horizontal and vertical axis. The rate of deposit cycles per shift would be

$$R_{AS/RS} = \frac{A \; H}{T_{CS}} \tag{7}$$

which can be compared to the required number of deposit moves per shift RSM to compute the required number of AS/RS robots

$$N_{AS/RS} = \frac{RSM}{R_{AS/RS}} \tag{8}$$

However, if multiple robots serve the same rack the length of the rack portion served by a single robot becomes $L_R/N_{AS/RS}$. This reduces the robot travel time so that $N_{AS/RS}$ should be iteratively computed.

Preliminary resources sizing is usually acceptable to carry out an economic comparison of alternatives. However the number of resources should be verified resorting to queuing based methods (Raman et al., 2009) or computer simulation to ensure that peak traffic can be handled and congestion problems do not cause interruption of material flows or line stoppages.

4. ECONOMIC COMPARISON

An economic comparison can be performed computing the Life Cycle Cost of the automated material handling alternatives which are deemed viable from the technical standpoint in the specific operational context. A performance measure is the net present value NPV

$$NPV = TCI + \sum_{k=1}^{N} \frac{F_k}{(1+i)^k} \tag{9}$$

where TCI is the total capital investment (including fork lifts, AGV vehicles, AS/RS robot, storage rack and ancillaries as required), F_k is the overall annual operating cost, i the discount rate (%/year) and N the material handling plant life.
In case the automation project is an upgrade of an existing manual handling system, then avoided future capital investments for equipment replacement and savings in operational costs (reduced workforce, lower material damage loss, reduced line stoppages) could be factored in as positive cash flows, and a positive NPV could be obtained as a justification for the investment. In this case even other economic performance measures such as the Internal Rate of Return (i.e. the i value that makes null the NPV value), and the Pay Back Time (i.e the time required to recover the initial investment and obtain NPV=0) can be used to assess the investment profitability.

In the literature, some capital investment data are available for racks and AS/RS systems (Hwang et al., 2002; Sule, 2009) but quotations from manufacturers should be obtained whenever possible. As an order of magnitude, the capital investment values shown in Table 1 could be assumed as a first approximation for the kind of equipment considered in this study. Data have been obtained from actual manufacturers and refer to mid 2009. Additional capital investment to be factored in are the cost of HW/SW systems and electricity distribution system upgrade, in house personnel training cost and production disruption costs. Table 1 also shows operational cost data excluding power consumption which usually is a negligible cost. In case space occupied by loading bays, storage rack and AGV facilities reduces available space for bulk storage in the warehouse, the cost of renting additional storage space in an external facility should be factored in (typical value 6-8 €/m^2 per month).

Table 1. Sample capital cost data

Item	Capital investment	Operating cost
Storage rack	130 €per storage location (+ 1600 €for rack erection each 150 storage locations)	
AGV system	115.000 – 150.000 €per vehicle	2500 €/yr (mandatory inspections, battery and vehicle maintenance); 3000 €/yr (battery change operators)
Fork lift	40.000 €per vehicle	50.000 €/yr (driver cost per shift); 4800 €/yr (maintenance per vehicle)
AS/RS robot	280.000 €per robot	15.000 €/yr (maintenance per robot)

5. CONCLUSIONS

In this paper the problem of automating the raw material handling process to feed continuous production lines has been discussed and a number of design alternatives have been proposed pointing out their relative merits and drawbacks. The analysis was focused towards the industrial sectors where heavy-large sized loads have to be moved and layout-constrained limitations exist as happens in the pulp and paper sector, or in sheet metal working industries. In such scenarios most of the material handling is carried out in a manual way giving rise to safety and efficiency problems. Suggested solutions are intended to provide a starting guideline for engineers involved in designing internal logistic systems as well plant managers evaluating the upgrade of manual MHS towards automated solutions. Some sizing and cost estimating criteria are given as well to allow a preliminary design of alternative systems and an economic analysis in order to choose the most cost effective solution. As a further research, in future works, a quantitative analysis will be carried out by comparing the above solutions in realistic industrial applications in order to assess the practical applicability of each solution and evaluate their economic performances. This will provide additional decision making insights to logistic managers.

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7. RESPONSIBILITY NOTICE

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