Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Conveyor Logistic Warehouse Merge Operating Area Throughput and Workload Balance System Research

Master's Final Degree Project

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Supervisor

Kaunas, 2019

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Industrial Engineering and Management (6211EX018)

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Declaration of Academic Integrity

I confirm that the final project of mine, Petras Viržintas, on the topic „Conveyor Logistic Warehouse Merge Operating Area Throughput and Workload Balance System Research“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand)	(signature)

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Task of the Master's final degree project

Given to the student – Petras Viržintas

1. **Title of the project –**

Conveyor Logistic Warehouse Merge Operating Area Throughput and Workload Balance System Research

(In English)

Logistikos centrų konvejerių susijungimo zonos našumo ir darbo krūvio paskirstymo sistemos tyrimas

(In Lithuanian)

2. **Aim and tasks of the project –**

Aim – To analyse and develop conveyor warehouse merge operating area working principle by improving throughput and keep balance in the system.
Tasks:
1. Analysis of warehouse structure and working principle, methods used for merge model;
2. Create new logical structure for more efficient solution for merge operation;
3. Research of merge operation using emulation software with connected programming logical controller for finding results of different methods.

3. **Initial data of the project –**

N/A

4. **Main requirements and conditions –**

Use of emulation software Xcelgo Experior 6.0;
Programmable logical controller S7-SIMATIC300 and SIEMENS Step7 software.

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Supervisor	Ramūnas Česnavičius		
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Petras Viržintas. „Conveyor Logistic Warehouse Merge Operating Area Throughput and Workload Balance System Research“ Master’s Final Degree Project, supervisor Assoc. Prof. Dr. Ramūnas Česnavičius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

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Keywords: conveyor, warehouse, logistic, merge conveyor, system balance, system throughput.

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Summary

Automated logistic warehouses is a large systems where all deliveries from arrival to departure point must be delivered in the shortest time. There is a lot of variables who determines result of fluent delivery time and to achieve best performance of the system, most complicated areas should be analysed and improved in the system. In this research was decided to analyse and develop automated warehouse conveyor merge operating area. Results are found of existing method and developed new algorithms to improve merge space utilization by increasing flow of parcel and keep system performance stable by using emulation model with connected programmable logical controller.

Petras Viržintas. „Logistikos centrų konvejerių susijungimo zonos našumo ir darbo krūvio paskirstymo sistemos tyrimas“ Magistro baigiamasis projektas, vadovas Assoc. Prof. Dr. Ramūnas Česnavičius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

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Reikšminiai žodžiai: konvejeris, sandėliai, logistika, susijungiamieji konvejeriai, sistemos balansas, sistemos našumas

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Santrauka

Automatiniai logistikos sandėliai yra didelės sistemos, kuriose visi siuntiniai nuo atvykimo iki išvykimo vietos turi būti pristatomi per trumpiausią laiką. Yra daug kintamųjų, kurie lemia sklandaus pristatymo laiko rezultatą ir norėdami pasiekti geriausią rezultatą, sistemoje reikėtų analizuoti ir tobulinti sudėtingiausias vietas. Šiame tyrime buvo nuspręsta analizuoti ir pagerinti automatizuoto sandėlio konvejerių sujungimo zoną. Naudojant emuliacijos modelį su prijungtu programuojamu loginiu valdikliu yra randami esamo metodo ir naujų sukurtų metodų algoritmai, kurie skirti pagerinti konvejerių susijungimo zonos vietos išnaudojima didinant našumą ir išlaikant stabilų sistemos veikimą.

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Introduction

Conveyor warehouse systems are a productive transporting method used in distribution centres of different types of packages through warehouse areas, but main task is to reduce cost of transportation and make delivery faster. Nowadays logistic warehouses and distributions centres are created on the basis of different optimization decisions. Warehouse Management Systems (WMS) became more important and complex, that causes quite hard to manage for consumer. On the market stands a lot of companies that can offer plenty of solutions with different possibilities and warehouse requirements. To choose best one and most of all suitable for process is not quite an easy task, because different criteria's that should be considered influencing it.

The Warehouse Management Systems are essence elements of the packages flow in logistic process and to optimize process structure. The most efficiency of a logistic centre is achieved when customer gets what he expects and is satisfied according to requirements he gave for project, with lowest cost and best performance.

Aim of the work:

To analyse and develop conveyor warehouse merge operating area working principle by improving throughput and keep balance in the system.

Goals for research project:

1. Analysis of warehouse structure and working principle, methods used for merge model.

2. Create new logical structure for more efficient solution for merge operation.

3. Research of merge operation using emulation software with connected programming logical controller for finding results of different methods.

Author Contributions

The results of the research carried out were presented at conferences:

- 24th International Conference "Mechanika-2019";
- The International Young Scientists Conference "Industrial Engineering 2019".

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The procceeding of the international young scientists conference "Industrial Engineering 2019":

- **Viržintas P., Česnavičius R.,** Automated warehouse conveyor systems merge operating area throughput and workload balance system research. Industrial Engineering-2019: Proceedings of the International Young Scientists Conference, 17 May 2019. Kaunas University of Technology, Lithuania.

1. Warehouse Process Overview

In a beginning trucks are arriving to warehouse inbound gates. After being registered at the entry gate, a truck parks its trailer in a parking lot. Then, a special trailer truck picks up a trailer and moves it to its dedicated receiving dock. A logistics worker opens the trailer, pulls a telescope conveyor directly in front of the trailer and successively unloads the parcels onto a belt conveyor. After unifying the loading segments of multiple inbound docks to a single conveyor line, parcels are automatically measured according to weight, size and address. If the receiver of a parcel was not recognized by the camera system, the parcel is discharged from the conveyor to one of multiple manual stations, where once identified parcels are reloaded onto the conveyor [1, 2].

After identification, a switch system successively loads the parcels on the main closed-loop sortation conveyor, so that a one-to-one mapping between parcels and trays is achieved and communicated to the background information system.

In modern warehouses, the sortation process is fully automated by closed-loop tilt tray conveyor systems. In such a conveyor system, parcels being unloaded from an inbound trailer and isolated onto separate trays of the conveyor system circle through the distribution centre until being tilted into the respective gravity chute serving the outbound truck dedicated to a parcel's destination. Typically, these conveyor systems are the bottleneck of the transhipment process and consume a large part of the investment into a distribution centre. On their trays, parcels travel along the conveyor until reaching their respective gravity chutes. Then, the tray is tilted and the parcel slides onto another telescope conveyor to be loaded into a trailer dedicated to the parcel's destination. Once a trailer is fully loaded, a logistics worker closes the trailer and communicates this status to the information system [1].

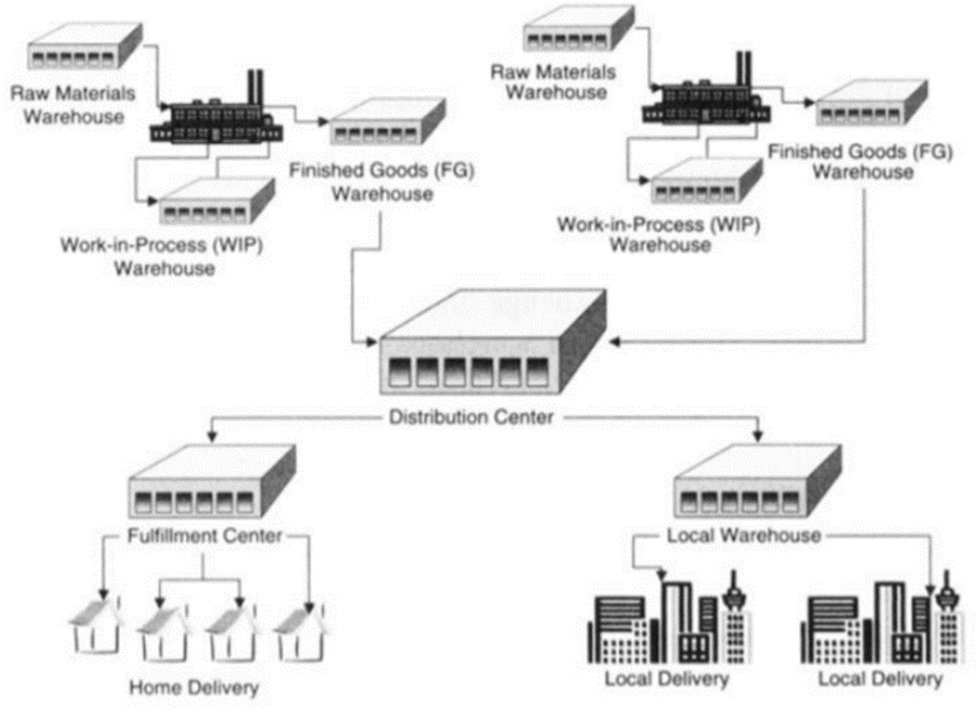


Fig. 1. Logistic chain

1.1. Logistic Warehouses Structure

Logistic Warehouses Transportation System is used to keep balanced number of deliveries variation between schedules and demand. To accumulate products from logistic faults of manufacture within firms for combined shipment to common customers, to shorten transportation distances and permit rapid response to customer demand [3, 4].

Functions of a warehouse could be sorted into several sections:

- Receiving
- Sorting
- Picking
- Shipping

Warehouses of today can deal with more complex and different possibilities such as [3]:

- Crossdocking – received deliveries are moved directly to outbound shipping to eliminate warehouse storage and order picking. It avoids bypass time and storage problems in the environment of the warehouse transportation. As well crossdocking provides a way to minimize inventories, space and labour in the warehouse.
- Receiving – collection of goods involved in the orderly receipt of all deliveries coming into the logistic centre, providing the assurance that the ordered materials will be in quantity and quality as ordered.
- Prepacking – performed in a logistic centre after products are received from a supplier and subsequently packaged separately in final look or in combinations with other parts from assortments.
- Put away – the act to put merchandise in storage. It includes a transportation and a placement component.
- Storage – physical containment of packages while it is waiting for dispatch. The form of storage will depend on the size and quantity of the items in inventory and the handling characteristics of the product.
- Order Picking – this process consist of picking items from warehouse to meet a specific demand. Order picking represents the basic service that the warehouse provides for the customer and function around, which most warehouse design based.
- Packaging – done as an optional step after the picking process. Individual items are boxed to provide safe delivery to customer.
- Kitting/ Customization – in this step goods are grouped, packaged or combined together to prepare a final product for shipment.
- Sortation and accumulation – sortation of batch picks into individual orders and accumulation of spread picks into orders, must be done when an order has more than one item and the accumulation is not done as the picks are made.
- Packaging and shipping- may include checking orders for completeness, packaging merchandise in an appropriate shipping container, preparing shipping documents, including the packing list, address label, weighing.

1.1.1. Conveyor types used in distribution centres

Conveyor material handling systens are built for continuous flow of deliveries. It lets to manage high volumes of parcels to defined paths [5]. A different variety of conveyor types can be integrated into a warehouse conveyor system, to ensure the best solution throughout the items handling process. Conveyor is available in various styles and is used in countless applications [6].

Conveyors in tote/ case conveyor structure [7]:

- Non-powered skate wheel and roller conveyor.
- Powered, belt and roller conveyor used in handling packages.
- Powered chain and roller conveyor used in handling pallet loads of goods.

1.1.2. Non-powered conveyors

Non-powered conveyor are the primitive form of conveyor which uses inertia or gravity to keep deliveries moving. These conveyors have two types: skate wheel and roller. Separate sections of non-powered conveyor often could be connected to unload packages from arrived trucks or load back. It can play a role as takeaway conveyor for cases coming from sorter, also it is used in workstations where needs to check or complete tasks by employees, after that delivery is pushed to other zone. It is very helpful when need to slow the inertia of products coming out from a high speed automated conveyors. Whether skate wheel or roller conveyors that moves products using inertia and gravity is common and used a lot in case/ tote logistic centres [10].

1.1.3. Powered package handling conveyors

Nowadays a lot of warehouse systems have powered conveyors because in these systems all packages are moved quickly and effective. On the market stands different types of powered conveyors but there are two main types that rule the market: roller and belt conveyors. The difference between these two types are that belt conveyor mostly are used to transport packages and powered roller conveyor has been used for accumulation. Also there are main criteria choosing between these types – what size of the package should be moved [8].

Belt conveyor – belt conveyor motor drives a disc which moves the belt. Belt can be made of different materials of surface – it could be glassy where items needs to slide or ribbed to ensure better grip between item and belt. Belt conveyors are not as expensive as roller conveyors, provides better properties of surface and it could transfer a lot of different types of products [10].

Roller conveyor – it lets to accumulate packages for a determined amount of time after that release in other segments of warehouse such as automated sorter or merge. Powered conveyors are divided in different types, it depends how the rollers are driven. Most common categories are [10]:

1. Line-shaft conveyor – through rollers are running metal shaft and with rubber o-rings connect the rollers to it. When motor starts it turns shaft and the shaft turns rollers it has been in the market for a long time, but it has limitations. Even though line-shaft conveyor costs less, it is parts-intensive, which leads to high maintenance requirements.
2. Belt-driven roller – under rollers mounted belt drives rollers. Belt-driven roller is a good accumulator because it is easy to create zones. It is very attractive to drop the belt away from the roller where you want to create accumulation.

3. Motorized roller – also known as internal motor or motor driven roller (MDR) conveyor. This type of conveyors are divided into sections, where at least one roller are connected to motor which drives rollers. Other rollers at sections are connected to each other by rubber o-rings. When motor starts rotating main roller others also start running. Motorized roller motors are usually used with low voltage motors. It is used because of less energy consumption than different types of drive motors and provides less torque and in this way make it safer. In case that each section is powered separate, sections can be programmed to run when package is present. This feature saves energy and decrease noise of conveyors. Motorized conveyors doesn't move as fast as different types of conveyor because it is smaller and uses low voltage parameters, but it creates more control and easier for maintenance purposes.

Segmented belt conveyor – innovation of motorized conveyors led to this type of conveyor. A section of segmented belt conveyor is essentially a section of motorized roller conveyor with a few feet of belting wrapped around each zone of rollers. It combines the accumulating power of roller conveyor with the stability of belt conveyor, resulting in excellent carton control.

Controlled flow conveyor – a mixture of non-powered and motorized conveyors led to controlled flow conveyors who can perform functions as align product to one side after that singulates it to a decline at a controlled rate. Maintenance for these conveyors are simple of modularity of the components and easy way of integration. These systems have a long time duration cycle, which allows to save money. In any manufacturing facility flexibility and ease of use are one of main factors [10].

In the figure below are shown companies of conveyor manufacturers and with what type of conveyors they are producing.

Conveyor manufacturers

			Package handling		Pallet handling		
Company	Web Site	Non-powered	Roller	Belt	Roller	Chain	Assembly-line conveyor
Ashland Conveyor Products	ashlandconveyor.com	x	x	x			
Automated Conveyor Systems	automatedconveyors.com	x	x	x	x	x	
Automatic Systems	asi.com		x	x	x	x	x
Automotion, a Wynright company	automotionconveyors.com	x	x	x			
Caljan Rite-Hite	caljanritehiteus.com						x
Carter Control Systems	cartercontrols.com		x				
Dematic*	dematic.com	x	x	x	x	x	x
Durr	durr.com						x
Fives Cinetic	fivesgroup.com	x	x	x			
Flexible Material Handling	flexmh.com	x					
FMC Technologies	fmctechnologies.com						x
Hytrol Conveyor	hytrol.com	x	x	x	x	x	
Industrial Conveyor	industrialconveyor.com						x
Industrial Cinetics	iki.com	x	x	x	x	x	x
Intelligrated	intelligrated.com	x	x	x	x	x	
Interroll	interroll.us	x	x	x	x		
InterSystems	intersystems.net	x	x	x	x	x	
Knapp	knapp.com	x	x	x	x	x	
QC Industries	qcindustries.com			x			
Roach Conveyors	roachconveyors.com	x	x	x	x	x	
SI Systems	sihs.com						x
Southern Systems	ssiconveyors.com	x	x	x	x	x	x
Swisslog	swisslog.com				x	x	
TGW Systems**	tgw-group.com	x	x	x	x	x	
TKF	tkf.com		x	x	x		

*merged with HK Systems in 2010; **merged with Ermanco

Fig. 2. Conveyor manufacturers [10]

1.2. Carton/Tote Conveyor Warehouse Areas Working Principle

The system configuration consists of the following elements [4, 9]:

- Inbound – where cases and totes arrives and things are prepared for distribution.
- Parcel Identification (PID) – to identify parcel for further packing.
- Tote De-Stacking – feed stacked totes into the conveyor network.
- Problem Solve – the operator is expected to remove the carton from the end of the lane and carry out one of the following functions – correct at source, return carton to inbound area.
- Happy Flow – cartons will move down the happy flow conveyors and onto the routing conveyors.
- Inbound Merge – merged totes will be transported to the shipping merge. The cartons will be transported on roller conveyor apart from a small section of inclined belt. Cartons will accumulate back if required.
- Main Sorter – totes and cartons are received from the main sorter and transported to the universal lines via decline belt or roller conveyors.
- Case Receive – lines receive cartons from the main sorter, take waste away to the waster conveyors and pass completed cartons to the shipping merge.
- Each Receive to Sort – inbound totes accumulate back from the most downstream point of the conveyor with no special logic deployed to distribute product along the lines.
- Waste Boxes – a series of belt conveyors that run continuously to transport waste boxes to the balers.
- Prep Lanes –receives empty double stacked totes from the main sorter on the top tier.
- Shipping Merge & Collector System – receives a mixture of cartons and totes from the Singulators, Each to Sort, Preparation Area and the Shipping Sorter recirculation. Any items sorted to the Jackpot can be fed back onto the sorter via the recirculation lane.
- Shipping Sorter - receives items from the shipping merge and sorts them to the required location.
- Fluid Loading Spurs – cartons will arrive at the fluid load lanes from the shipping conveyor and move to the boom conveyors.
- Tote Robot Palletising Spurs – totes are transported on accumulating roller conveyor to a robot interface position. The conveyor side guide is used to funnel the totes into the correct position for the robot.
- Manual Palletising Spurs – operators take cartons from the lines and manually stack them onto pallets.

The above areas are combined in the combination which is shown in Fig 2. The overview describes the main flow paths, for a more detailed description of the process flow.

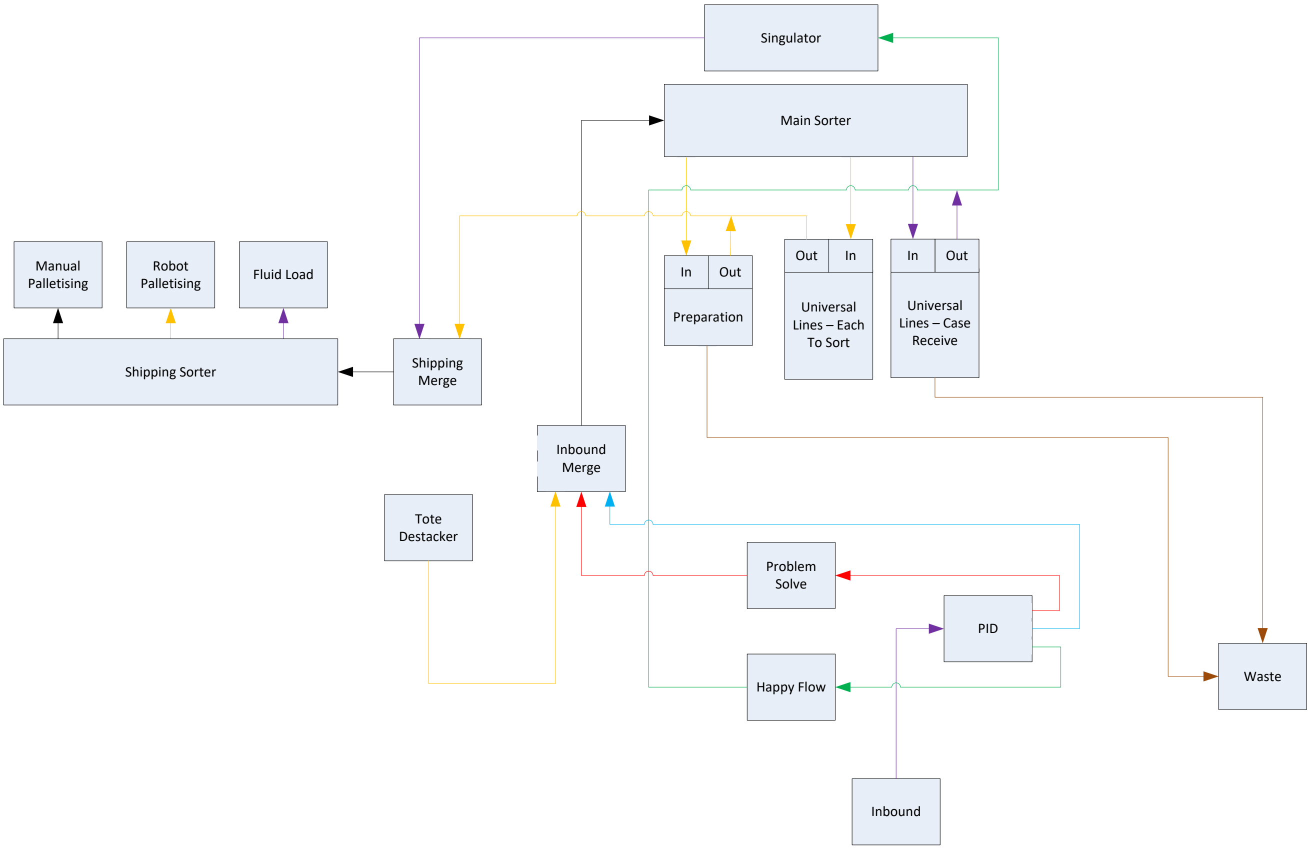


Fig. 3. Process Flow Diagram.

1.3. Analysis of research problem

This research is made based on the merge area analysis in logistics warehouses conveyor systems. Throughput analysis is important to design of layouts, operation system and management of production improvement [11]. Working principle is based on alternating methods aspects by changing flow from lines, to achieve best result in space utilization of merge zone.

In this case three lines merge to one line conveyor throughput efficiency and balance of the system is analysed, how it works with different parameters and what method will show best results.

Fig. 4. Merge conveyor

To balance system workload need to know flow of main line and all infeeds. If all lines are full and one line spreads more parcels than others, than will be lost balance between conveyor lines. All infeed batches should be served at the same amount. When workload is balanced through main merge line and infeeds, all batches will be delivered at reasonable time that could be [2]. But it depend how is used all lines, if before merge area in main line comes another infeeds and in that case main line would have more workload what causes more throughput from main line than from infeeds. Relocation actions for conveyor lines can be done by splitting workload through infeed lines. It is done by changing line to make all lines same loaded.

All indicative parameters are expressed in time form. Between all deliveries are gaps which are one of main factor in merging area. When the gap is large enough to locate delivery from infeed and there is enough time to spread it into empty space, then infeed start flow of required output to the merge area.

To maximize throughput needs that on the merging area would be enough space to implement parcels and do it as much as possible with most space utilization on main line. In this view of logic the conveyor space should be utilized in a best way through merging area. Measuring and varying with time parameters for infeeds to merge main line can allocate space gaps and times when actions needs to be taken when all logic starts in automated warehouses [12].

1.4. Merge area

In Fig.5 is shown merge area, which is analysed in this case. Main line is horizontal line where parcels are coming from other areas and on the right side is connected two infeeds that can be used from another lines such as – packing, assembling or similar. Both inbound lines should be merged to the main line. The main function of merge – to collect deliveries from different lines and sort it to outfeed points [13].

On the merge conveyor, the direction of the flow is referred as downstream and the opposite direction as upstream. In this area are specified main points of the process: Merge space request points, merge point.

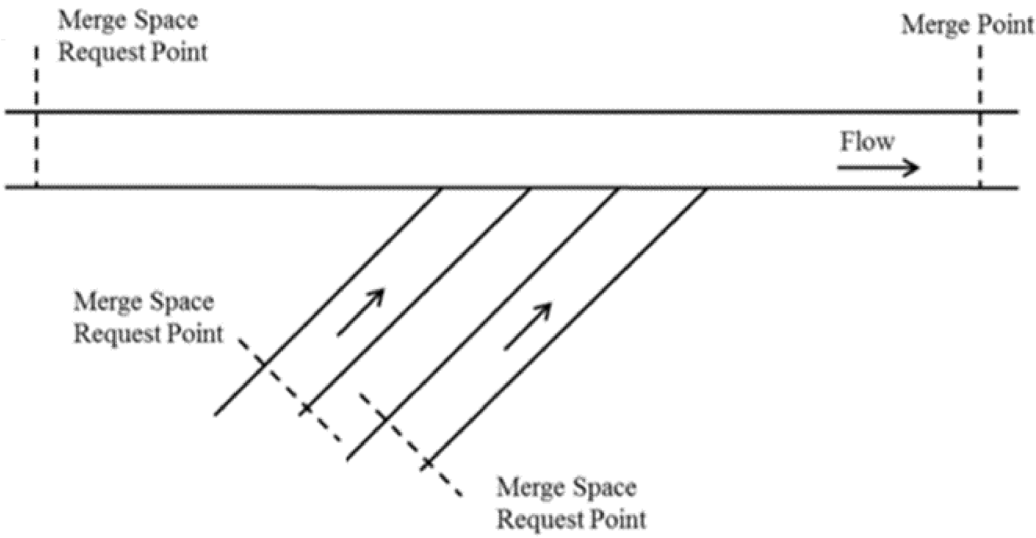


Fig. 5. Merge area

Merge Space Request Point

Merge space request point is the point at which parcels stops and waits for actions to be taken in merge logic. As delivery reaches this point, system gets signal that parcel occupied sensor and is ready to be merged. When other lines spread required amount of boxes, then requested line is spread to main line.

Merge Point

The last sensor on the merge area is merge point. It is straight after all infeed lines. This point means end point of merging conveyors which notices about finished cycle through one line.

2. Methodology analysis

In this chapter literature sources are analysed where topics with information required for merge zone performance research are described. In these scientific papers modelling view of merging area, scheduling and algorithms of different methodologies of prioritizing lanes for achieving more reliable, stable and compliant system are analysed.

2.1. Dynamic and static approaches

In this literature review modelling the merge area workload balancing and throughput maximization objectives is described. In this review closer look to static and dynamic approaches is taken [14].

Static approach where a closer look is taken at moment of merging area with parcels on lines and try to examine it and find best solution for throughput and workload balancing. It can be used repetitive times, because different amounts of parcels on each infeeds and different empty slots on merge area. This type of method leads to analysis of logic design, how merge area should be done and if there is needed any changes in allocation decisions.

Using Mathematical model is very similar to static approach which takes to specifically optimization issue. By static method, when all required data should be given as constant values for solving the task.

Static view decision variables, when is needed to know the first tray for infeed parcel (f, p), another deliveries placed on the parcel, depends just from length of downstream conveyor. To avoid collisions in merge points and keep required distance between trays are used special variables:

Waiting time of each infeed parcel is defined as time gap difference between first delivery assigned to infeed parcel line and available first tray on main line $d_{f,p}$:

$$W_{f,p} = \sum_{t} t \cdot X_{t,f,p} - d_{f,p} \quad \forall (f,p) \in P \tag{1}$$

The average waiting time ($AvgW_f$) for parcels in infeeds are calculated by dividing all parcels waiting time from amount of infeeds:

$$AvgW_f = \frac{\sum_p W_{f,p}}{m_f} \quad \forall f \in F \tag{2}$$

Static approach of total waiting time (ToTWf) have two different expressions:

1. Static approach of total waiting time (TotWf) on an infeed is determined by difference of the waiting time and time available to merge of end parcel. Mathematical expression for ToTWf:

$$TotW_f = \sum_{t} t \cdot X_{t,f,m_f} - d_{f,m_f} \quad \forall f \in F \tag{3}$$

2. View of $TotW_f^{`}$ takes attention of what length parcels and how loaded infeeds are. This view first let merge heavily loaded lines than infeeds with few deliveries. In this view, need to multiply $TotW_f^{`}$ by how highly loaded infeeds are and gives priority to more useful line:

$$TotW_f' = \left(\sum_{p=1}^{m_f} l_{f,p}\right) \cdot \left(\sum\nolimits_t t \cdot X_{t,f,m_f} - d_{f,m_f}\right) \forall f \in F \quad (4)$$

In this literature source author's main point is to make waiting times minimum as could be. To find minimum value of longest waiting times is used comparison for imbalance between TotWf and $AvgW_f$ which can be expressed as sum of both variables:

$$\delta \cdot TotW_f + AvgW_f \leq imbalance \quad (5)$$

Imbalance comparison between $TotW_f$ and $AvgW_f$ is attributed to parcel with longest waiting time. The point of model is to get as similar delays for infeeds as possible what leads to more reliable and balanced system. This method is more suitable for system balance than to achieve optimal throughput, but pretty accurate achieved numbers is fairly enough to investigate throughput and system balance of merge area.

Static approach was conducted, which resulted 100% space utilization and balanced workload. But finding best result to achieve optimal solution with static method takes time up to 32 seconds, where in online conveyor system decisions should be taking as fast as possible which means it should react and make a decision in milliseconds. This approach have negative features to use it in online working systems, such as finding best logic mathematical model can be interrupted without finishing of finding best solution, batch type parcel place allocating is not the common method to spread parcels to main line.

Dynamic view of space allocation is related with live conveyor systems. This approach is taking care of empty space on main line at a moment which could be filled with deliveries from infeed lines. Possible delivery to empty space on main line could be which meets the requirements for space window. This analysis method is based on precedence logic.

When empty place is detected on main line, then priority will be given to infeed with highest tray number on it for throughput measure:

$$ThroughputMeasure_{f,p} = \frac{l_{f,p}}{sw} \; \forall (f,p) \in C \quad (6)$$

Infeed could fit to space window and a balance measure which consists of total time which is needed to spread trays from that infeed to empty space on main line:

$$BalanceMeasure_{f,p} = \frac{TotW_f}{\sum_{f' \in F'} TotW_f} \forall (f,p) \in C \quad (7)$$

Priority logic is based on fulfilment of parcels spread from lines and balancing of flow. It is expressed in formula:

$$priority_{f,p} = \alpha \cdot BalanceMeasure_{f,p} + (1-\alpha) \cdot ThroughputMeasure_f \quad (8)$$

In this method as well is used imbalance variable for balancing merge area and described as difference between infeed with longest TotW and infeed with shortest TotW:

$$ImbalanceWT = \frac{max_{f\in F}\{TotW_f\} - min_{f\in F}\{TotW_f\}}{max_{f\in F}\{TotW_f\}} \cdot 100\% \qquad (6)$$

Dynamic approach aims to fill conveyor space completely and optimize imbalance value.

In Haneyah literature source was done simulation to find results of dynamic method. Differences in workload balancing by changing priority parameter and in result had no significant value for merging area utilization and balancing the system. Main difference is when from pending request parameter 0 change to any other value, difference is about 13%. Best results was achieved with alpha value 0.8 where best result get for utilization 86.88% and imbalance reached 4.43%.

The Priority based method could be used for any amount of infeed lines, because there is the same logic which repeats for each line. This method commonly is used for infeeds with long downstream lines to see all coming deliveries and make logical calculations for the system. Shorter systems can cause accumulating problem and huge impact for balancing deliveries. In conveyor warehouses where main task is to achieve better throughput and not 100% in balance this approach is more suitable.

2.2. Scheduling approaches

Methods of scheduling CPU is described in Andysah Putera Utama Siahaan literature source by comparing three different models of scheduling central processor unit: First come first served (FCFS), shortest job first (SJF) and round robin [15]. For each method was calculated total waiting time (TWT) and average waiting (AWT) time with variable parameters of arrival time and burst time. To find AWT first need calculate waiting time of all processes. Sum up all of them and dividing from number of processes is getting required value which can be expressed from these expressions:

$$WTn = \left(\sum_{t=1}^{n-1} BT\right) - ATn \qquad (10)$$

$$TWT = \sum WT \qquad (11)$$

$$AWT = TWT\ /TOTAL\ PROCESS \qquad (12)$$

In this case was used 25 processes where each process have their arrival time and burst time. Result of calculations for first come first served method average waiting time got 13.12 value, for shortest job first got 12.36 time value and round robin method was done in several amount of quantum time (QT), where process burst time is divided into several parts. With different parameters of quantum time best results was achieved with QT of 5 which resulted 13.84 time value. Important thing in round robin method, that if QT value is higher than process burst time, this method is no longer the same and changes to first come first served method.

From this thesis can conclude that all methods have different working type and adaptation to different requirements. The first come first out method could be achieved best results with low burst time value processes, shortest job first method best conditions would be to work when processes came at the same time. Round robin method should be used when needed accommodation for average is waiting.

In another work is described algorithms for operating systems, where given task remains the same for process and dynamic while decisions making is done in run time. In this source are compared four algorithms: Earliest deadline first (EDF), adaptive scheduling, genetic based scheduling algorithm, ant colony optimization (ACO) [16].

Each method have their pros and cons. EDF algorithm is based on dynamic approach and priority goes to that process which has closest deadline to be done. Parameters on which depends this method is such as fill level of each line, release time, when it started and when should be finished, accomplishment. This method has disadvantage for high volume processes and to avoid failures in the system is used adaptive algorithm. ACO method is working as natural ants that each of them makes a trackway and all of them are an option at the same time. Separate ant represents her journey from various point of trackway and prioritized by importance and repetition of delivery. Other one is genetic algorithm, it is based on repeat after generations same process again. By memorizing required information and keeping it until needed. This method learns from past actions and group similar parameter to make sure of future possible same processes and put in priority best process. Adaptive method consists of earlies deadline first and ant colony optimization and commonly used for improvement to balance the system. Logic of this algorithm is if lines are not loaded use EDF method prioritize processes by deadline and if flow of the system is high, then EDF is changed to ACO method and counting parameters of fastest process and implementation of whole processes at the time.

After comparison of all methods was decided that EDF have better parameters when system is with low flow than ACO, otherwise EDF is not such good as ACO or genetic based algorithm when system is highly loaded. After these conclusions by source authors was created an adaptive algorithm which is working well in high and low density of processes. In this method is used EDF and ACO algorithms and the best method is used.

Operating scheduling systems are not looking to start operational schedule until it reaches start point of the system and by Goel and Sharma, process can be divided in to two group: computational intensive which requires higher central processing unit speed and communicational intensive which requires fast transfer of information. Most optimized scheduling algorithm by authors is shortest job first and could serve in any kind of work. With this method is achieved minimum average waiting time and average turnaround time. Mostly used algorithm is described as mostly used, because it is dividing priorities by time spend for all actions and it is very similar to first in first out method. Between first in first out method and shortest job first stands not a lot of differences, but in more often better results is achieved with shortest job first method [17].

As well for communication processes is very important location of main cabinet and devices to avoid failures in the big system, that leads to divide all site into smaller PLC areas where it is split into functionality of group conveyor

2.3. Merge control algorithms

Close look to conveyor warehouse handling system merge area is taken by M. Johnstone where compared FIFO algorithm with different parameters and how they affect performance of warehouse merge system [18]. In this case is analysed closed loop conveyor system where windows method can be implemented. Using windows for tracking in the software is made that module automatically generates the signal to start the transport for the next waiting tote and software automatically occupies window and reserves it. This method is used for an input or an input/output conveyor-lines in a closed loop [19].

For merge area is described allocation rules such as First in first out which was described in previous source, infeed line priority gives route to infeed line and from main line parcels are spread only when space gap is allocated and it can be in opposite way. Merge flush – implement parcels from lines when it is accumulated at described number and then spread to merge area. For this rule can be given time period in which parcels should be spread than accumulation number of parcels.

Between comparisons of methods in throughput performance were done analysis with different length of merge point. In result it showed that with each merge point was achieved using variable length method.

3. Analysis of merge operating area

First step of analysis, need to know all system parameters and values which will be used for emulation model creation and parameters in software. With required values can be done analysis of existing FIFO algorithm. Main task for system performance improvement was chose methods without any changes in conveyor design, what is cost effective.

From analysed methods from literature source and layout type of merge conveyor was decided to use method with priority flow from main line and create gaps to implement parcels from infeed line. One method will be created with same length gaps and implementing parcels from infeeds with FIFO algorithm. This method requires only changes in software.

Another method will be created for different length of parcels by creating varying length gaps on main line. For that need to know infeed parcel length which requires implement additional hardware configuration to conveyor and new software design. Infeeds will spread parcels with FIFO function to achieve best results in system balance.

After design of software emulation model will be generated and system tested with created parameters from logical programmable controller which later are used for real operating conveyor systems. Emulated results are collected and used for analysis of methods and achieved results.

3.1. System parameters

The analysed system is designed for tote and case deliveries. Tote dimensions are fixed, but cases parameter can vary and depends from size of delivery:

Table 1. Totes size parameters

Description	Length (mm)	Width (mm)	Height (mm)	Weight (Kg)
Minimum	600	400	305	0.5
Average	600	400	305	12.3
Maximum	600	400	305	15

Table 2. Carton cases size parameters

Description	Length (mm)	Width (mm)	Height (mm)	Weight (Kg)
Minimum	228	162	210	0.45
Average	508	408*	300	2.72
Maximum	565	397	345	15

Conveyor speed is 1m/s and acceleration of conveyor is 2.5m/s. In case to reduce collisions and make system more reliable in faults, system accumulation conveyors have parcel windows length of 770 mm while maximum length of delivery is 600 mm.

In perfect conditions conveyor with 100% space utilization of merge area should achieve 5454 deliveries per hour, but window size is increased by fixed gaps of 170mm to avoid collision in all routing processes and this leads to throughput loss and total of 4675 deliveries per hour in perfect conditions. Making system reliable and effective, increased gaps reduces total throughput by 16.6%, but stable system have less possibility to get fault in parcels collision.

Analysed merge areas is designed in the last point just before sorter system where it goes from roller driven conveyor sections to belt section. Just before sorting section there stands belt type merge:

- Belt merge is designed for slug-infeed-lines into one belt.
- From the merge-belt the slugs are sent to the infeed of a sorter.
- The merge is used to collect all deliveries from different warehouse areas
- The maximum throughput-performance for the sorter.

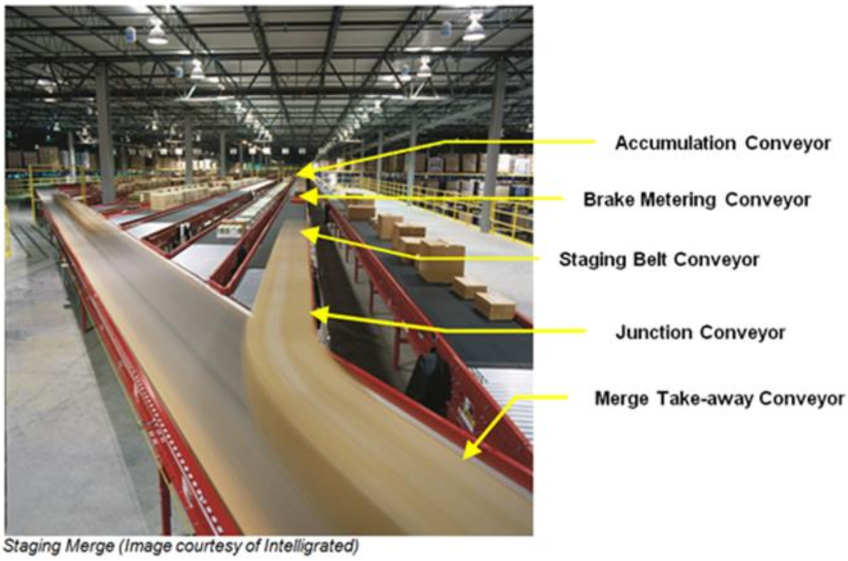


Fig. 6. Slug belt merge conveyor [20]

The Merge provides a saw-tooth merge arrangement consisting of different input lines – Tote De-Stacking, Problem Solve, PIDs Inbound and Recirculation. Each merge line accumulates product on roller conveyor before using a combination of 3 preparation belts to gap, measure and index cartons onto the longer slugging belts.

The slug building arranges cartons together with predetermined small gap between them. The index belt and a slug belt work together to perform this function. Slugs are created by indexing the slug belt forward to receive individual cartons onto the charge end of the belt.

The slug build section consists of series of conveyor sections with specific functions as shown below.

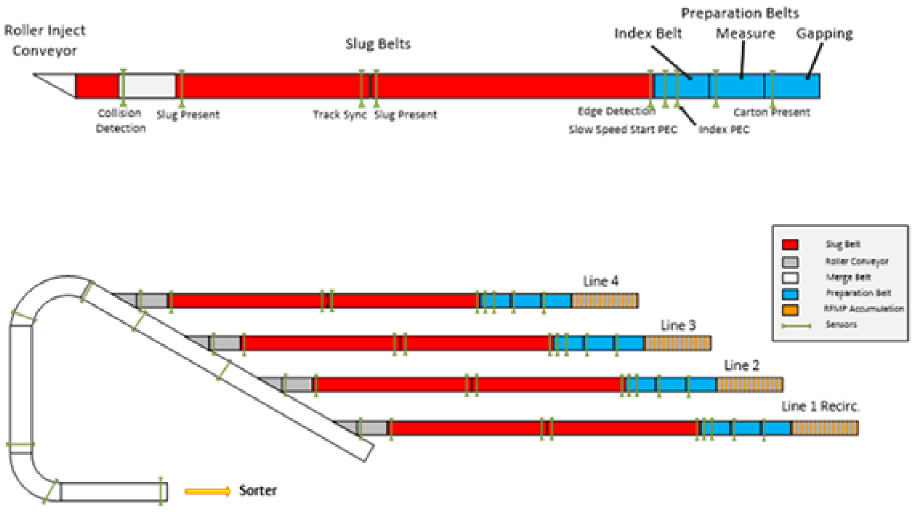


Fig. 7. Slug belt merge conveyor structure

Sorter system speed is higher than all system and could be set up to 2.5 m/s. Before entering sorting area there are gaper belts, where required gaps are set for sortation. The gaps between parcels are checked and corrected if necessary by the dynamic gaping unit and diverted at the desired positions [20].

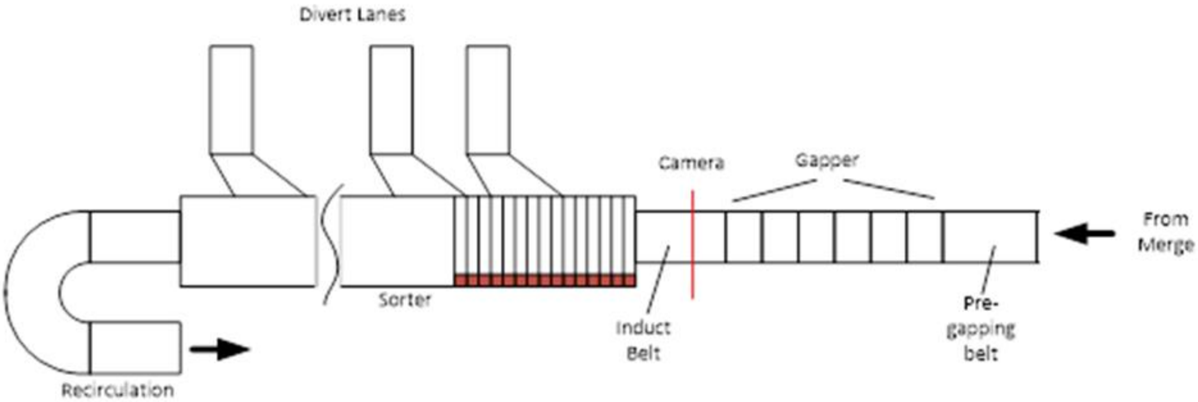


Fig. 8. Sorter conveyor structure

The dynamic gapping unit is made up of:

- One infeed belt, driven by a SEW Movimot drive with an encoder.
- Six gapping belts, driven by servo drives with resolvers.

The gaps between deliveries are checked and if necessary adjusted by varying the speeds of the 6 belts. Every time a delivery enters the infeed belt, as seen in figure above, its front and rear edge is tracked and its length is measured. While parcels travel over the infeed conveyor, a correction value that should be applied to the gap is calculated. By default, the speed of each belt matches the speed of the sorter. If correction is required, correction belts further adjust their speed using ratios to obtain the desired gap between cartons. For example if delivery arrive with a larger than desired gap, belts will adjust the ratio to decrease the gap.

To keep the actual position of any carton as precise as possible, the tracking position of every photocell is known and is used to update the delivery position during its movement. In that case before sorter area gaps between coming parcels could be reduced and increased throughput of the system.

3.2. Merge area conveyor types

In merge area are used two types of conveyor:

- Accumulation conveyor
- Transport conveyor

Bellow in the next chapters are described functionality of these type conveyors

3.2.1. Accumulation conveyor

Each line before merge area starts with accumulation belts or rollers. The accumulation conveyor in light aluminium construction is used for the conveying of totes and cartons.

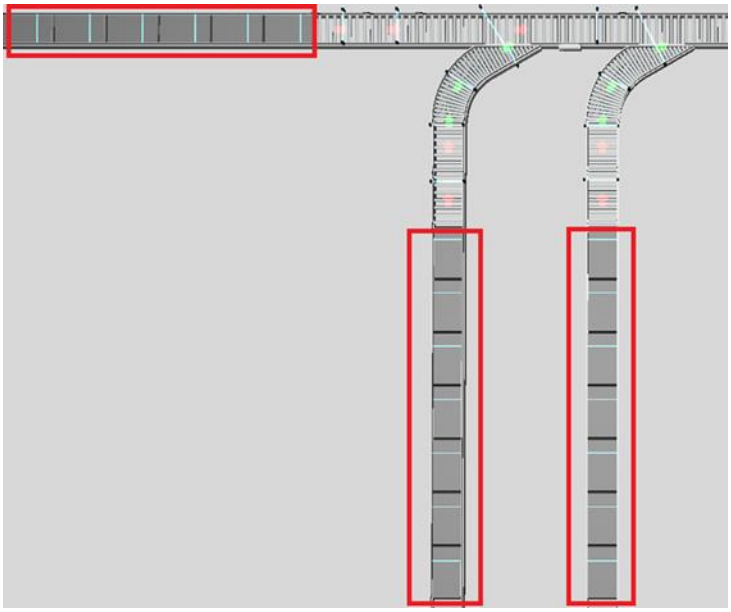


Fig. 9. Accumulation zones

When configured as an accumulation section, the roller conveyor section behaves as a single drive equivalent but with an embedded accumulation function. Each accumulation zone will be a defined system length and fitted with an accumulation PEC sensors. This accumulation function is embedded within the controller independent of the PLC logic. The PLC has control of the release function (Discharge Zones) and monitors the fill level (Charge Zone).

The rollers are controlled by a conveyor controller. The accumulation function inside the controller is connected via Profibus interface to the PLC. Through this interface is possible for the PLC, to control the first two zones in the front. The other zones of the accumulating conveyor are completely controlled by the conveyor controller.

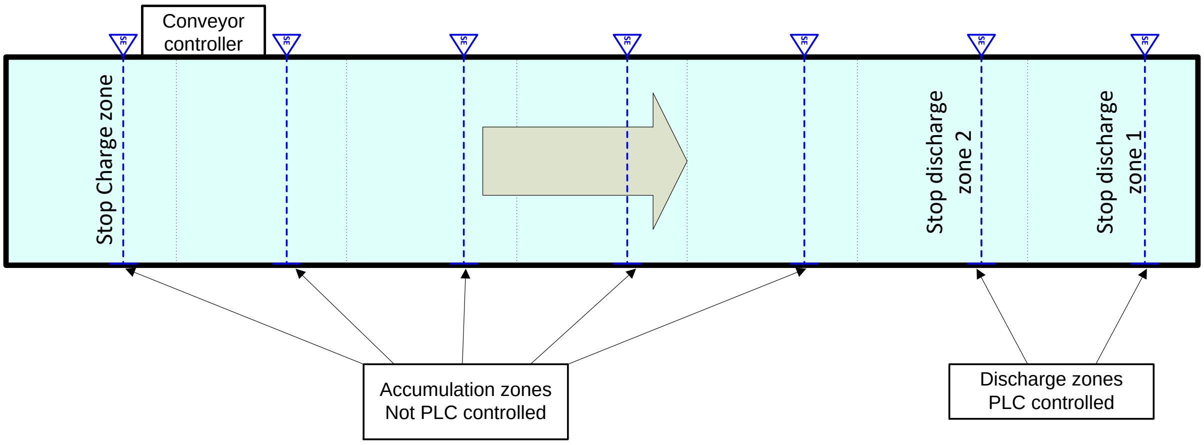


Fig. 10. Accumulation zone structure

These are the first two zones in the front on the accumulation conveyor. The discharge zone 1 and discharge zone 2 are controlled by the PLC. Only roles, which are necessary to move the box on the conveyor are running. After the energy save mode timer has expired, the rollers in the accumulation zone stops. The energy save mode timer for the discharge zone 1 and discharge zone 2, can be adjusted in the PLC.

The roller conveyor equipment based on gearless motorised rollers as drive technology in the main. This system is supplied by means of 48 VDC on the power side and 24 VDC on the electronic side. Conveyor system also offers the possibility to directly process digital inputs/outputs and to communicate with the PLC.

A light barrier at every accumulation zone is used to start and stop the movement from one zone to other. By default, the photo eyes from the discharge zone 1, 2 and the charge zone, send the actual state to the PLC but is also possible to configure the controller to send the state from every photo eye on the accumulation conveyor.

Two different transports are implemented at this software module:

- Transport from the conveyor in front direction – In this case a tote is on the conveyor and the handshake transport is started with the enable signal.
- Transport to the conveyor in rear direction – the transport of a tote from the conveyor in rear direction is started if the Output ready signal is set and when there is no error.

Module parameters

The important module specific parameters are mentioned here:

- **TiOffWaitDisPos2** – timer off delay waiting for transport discharge zone 2. This is the waiting time for the tote at the discharge zone 2, after the tote at the zone 1 has started the movement.

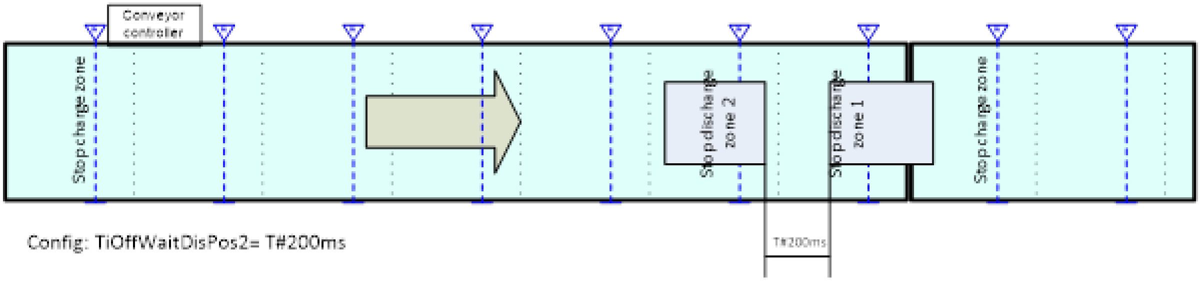


Fig. 11. TiOffWaitDisPos2 working principle

- **TiOffWaitDisPos1** – timer off delay waiting for transport discharge zone 1 to generate a constant flow out of an accumulation conveyor a timer can be used if a parcel has released the accumulation conveyor a timer starts. If the timer has expired the next parcel is enabled to start.

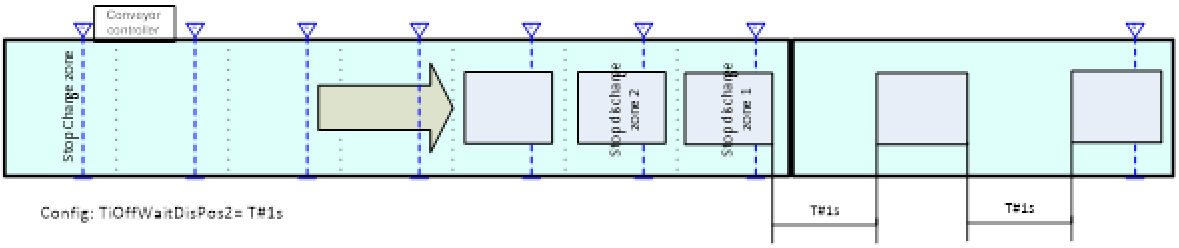


Fig. 12. TiOffWaitDisPos1 working principle

- **TiOnAccSig** – timer on delay accumulation signal. This timer is a condition for the takeover ready signal. The accumulation conveyor is ready to take over, when the charge zone runs, and the timer on delay charge signal at this position has expired.

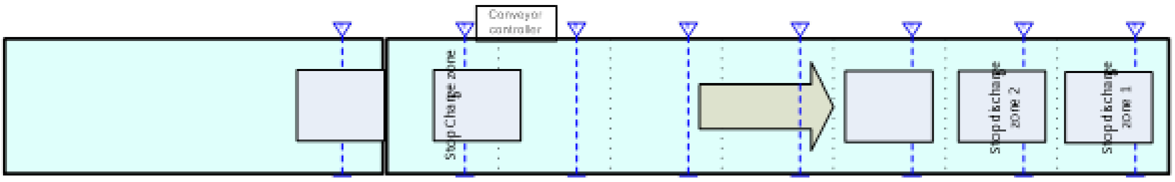


Fig. 13. TiOnAccSig working principle

- **TiOnDisPos1** – timer on delay discharge zone 1 signal.
- **TiOffDisPos1** – timer off delay discharge zone 1 signal. Is used to build the hand over ready, and the hand over end signals. The conveyor is hand over ready so long as the TiOffDisPos1 signal is high. The hand over end signal is sends, when the TiOffDisPos1 has expired, and the take over is active.
- **TiDelTrspInt** – timer delete internal transport (0=inactive). It is meant the internal transport to the charge zone.
- **TiOffMainConOff** – timer off delay main contactor off signal. Sent errors from conveyor controller to the conveyor software module, are evaluated only after the TiOffMainConOff expired.
- **MaxNoLCs** – maximal numbers of totes on the conveyor. Activates the takeover mode, according the fill level. MaxNoLcs=0 this mode is deactivated.

- **LCsTrhld** – maximum of totes on the conveyor, after the QX_FillPreMsg is set. Activates the takeover mode, according the fill level. LcsTrhld=0 this mode is deactivated. Till the QX_FillPreMsg is not set, the conveyor is always takeover ready. If the QX_FillPreMsg is set, the conveyor is takeover ready only when the charge zone runs, and the timer on delay stop charge zone at this position has expired (only progressive mode), or the photo eye at the charge zone is free (not progressive mode).
- **Vel –** adjust the roller velocity at the conveyor.
- **Accel –** adjust the roller acceleration at the conveyor.

3.2.2. Transport conveyor

When configured as a transport section, the roller conveyor section will behave as an equivalent single drive. All motorised rollers declared within the single function will start and stop together based on the run signal direct from the PLC.

Fig. 14. Transport conveyor sections

The motor rollers on conveyor A rotates so long until the STOP-Fro light barrier is reached. To continue the transport, the forthcoming conveyor B must be ready to take the cartons or totes. Also when no more boxes are moving after a time the conveyor goes into a power save mode.

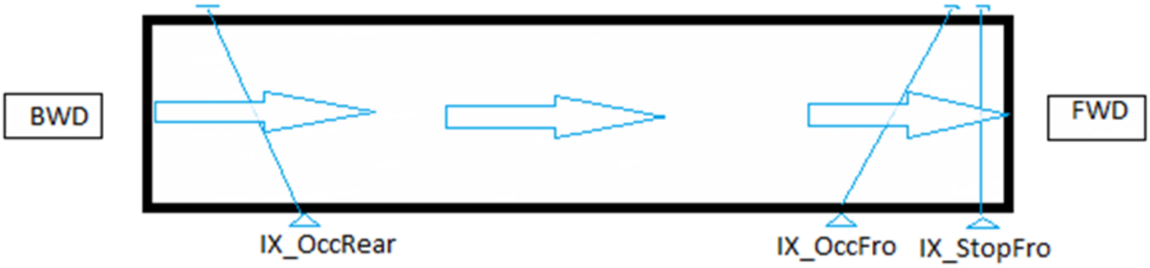


Fig. 15. Transport conveyor structure

Light Barriers:
1. Stop Front
2. Occupied Front
3. Occupied Rear

At the end position one light barrier Stop-Front is necessary to stop the movement. If after the stop the Occupied Front light barrier is occupied then the Conveyer is not more ready to take other Articles from the rear and the drive is no more moving because the collisions should be prevented. The IX_OccRear is an optional input for creating gaps between boxes.

Two different transports are implemented at this software module:

– Transport from the conveyor in front direction – in this case a tote is on the conveyor and the handshake transport is started with the enable signal IX_EnDpFro.

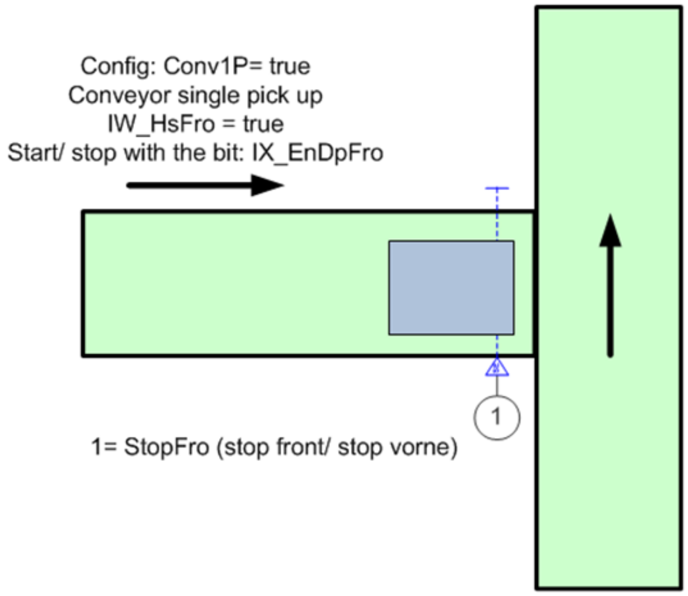


Fig. 16. Transport from the conveyor in front direction

– Transport to the conveyor in rear direction – the transport of a tote from the conveyor in rear direction is started if the Output
– **QX_TORdy** – is set and when there is no error (see an example picture below). The drive stops if the timer Para.TiOffESM has expired.

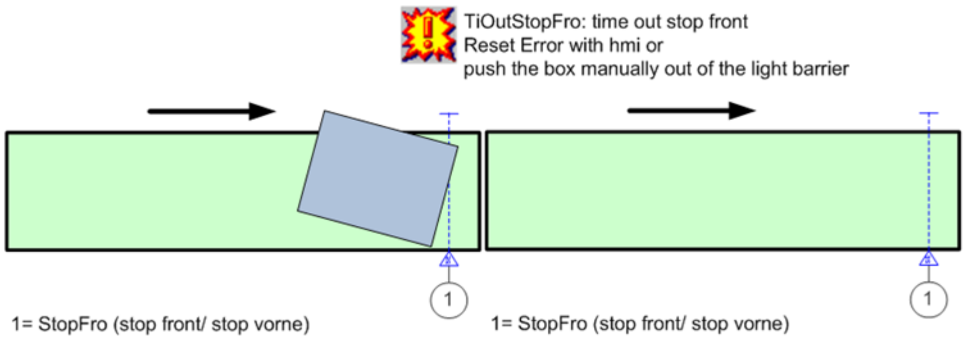


Fig. 17. Take over ready function

To start the transport, the following signal states are important:
IX_OccFro should be false.

IX_StopFro should be false.
IX_ExtFwd when not use set to state 0.
IX_EnPuRear when not use set to state1.

IX_EnDpFro when not use set to state1.

Module Parameters

The important module specific parameters are mentioned here. For standard parameters have a look at the standard documentation:

- **Para.ModCfg.Conv1P** – conveyor single pick up 1=active 0= inactive. If this parameter is set then this means that the conveyor is able to take only one box. A second box must wait on the previous conveyor, till the first one is delivered.

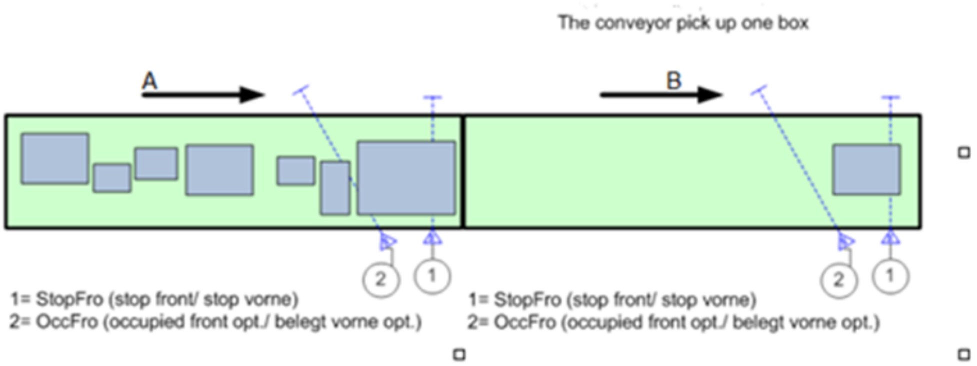


Fig. 18. Para.ModCfg.Conv1P working principle

- **Para.ModCfg.SimuDpPu** – simultaneous deposit and pick up. If this parameter is set then this means that the conveyor takes a packet and at the same time delivers other packet (see picture below).

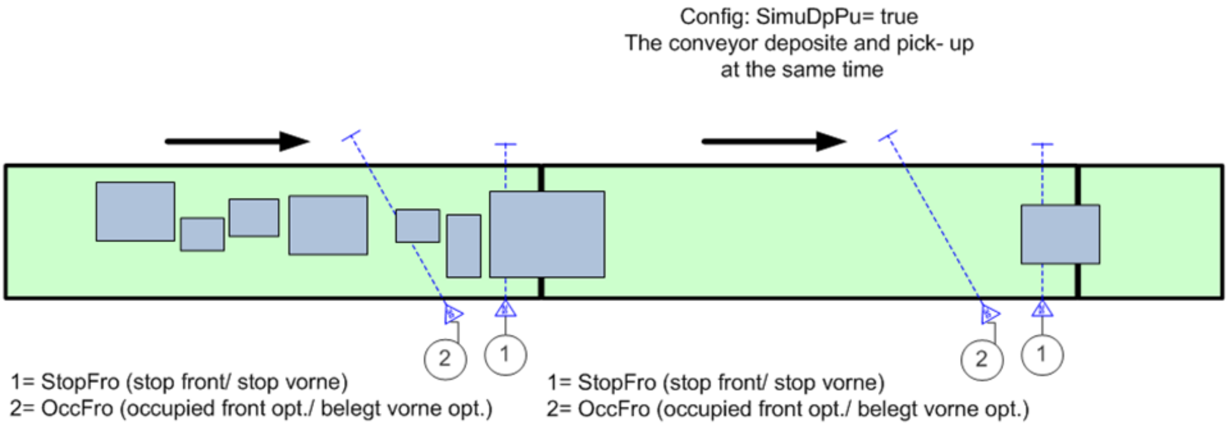


Fig. 19. Para.ModCfg.SimuDpP working principle

- **TiOnStopFro** – timer on delay stop front – The timer to stop the tote when the tote reaches the light barrier during a transport from the conveyor in rear direction.
- **TiOffStopFro** – timer off delay stop front – The timer to stop the drive when the parcels leaves the conveyor in front direction. The conveyor is ready to receive the next load at this moment.
- **TiOffWait** – timer off delay waiting for transport. It can be used for creating defined gaps between boxes. The photo eye used to determine the gap is the IX_StopFro. If the timer is set for example to 1s, and the gap is smaller than 1s, the second box wait the rest time and, than follow the movement. So, the gap between boxes in these case will always 1s (see picture below).

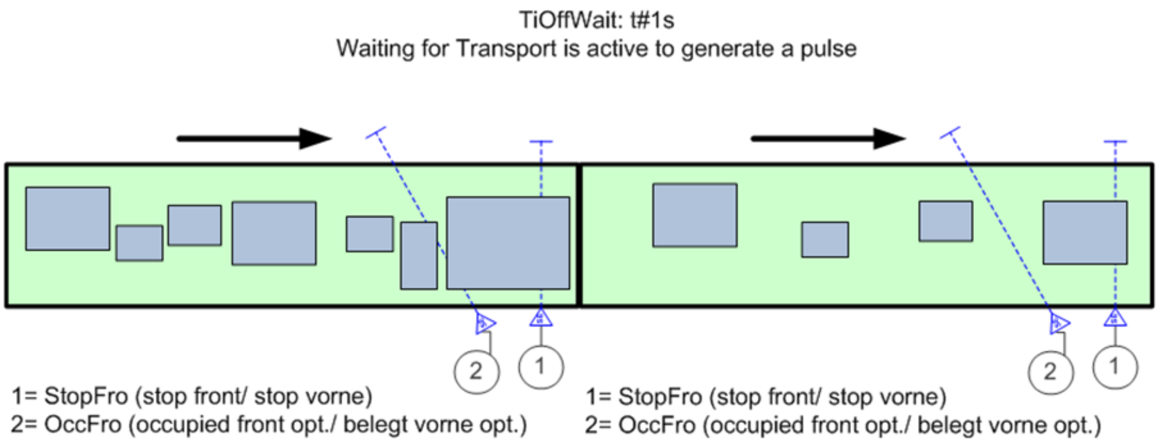


Fig. 20. TiOffWait working principle

3.3. Conveyor merge zone main points

In working merge operating mode conveyor infeed sections on the main line will turn constantly. The merge is operating in the following way:

- Arriving cartons will travel through the merge point if it is clear to do so.
- Once a slug is released the configured number will be passed through the merge. Once the number has passed through the other feed will be released for the configured number of deliveries.
- The configured number can be different between feeds to prioritise one feed over the other.
- If no parcels has been arrived for a certain period of time across any of the infeed lines, then the control mode will skip it and will work with rest of lines.

3.4. Logic working principle

When conveyors are running separate, then can be started modifying merging function. First of all there is set merge request point shown in fig.21 at this sensor boxes stops and waits for their turn to go through merging zone.

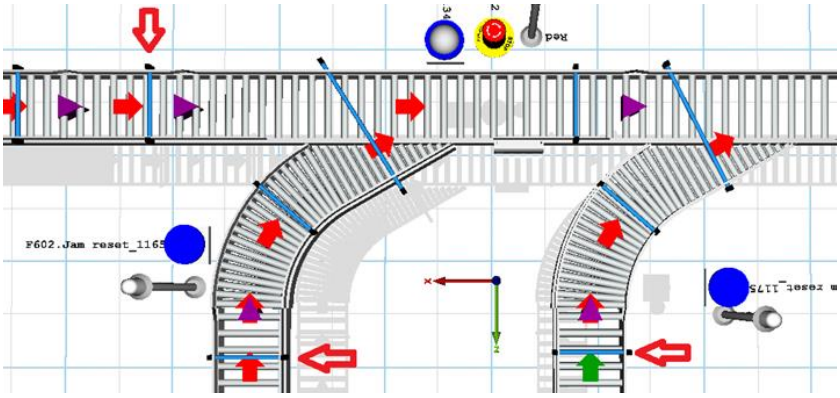


Fig. 21. Merge request point sensors

Sensors shown in fig. 22 is used to locate a parcel going through merging area. In the system are additional sensors to help manage system performance when occurs collision of parcels. In that case parcels are stopped at these points to wait until occurred jam will be cleaned. After stopping system starts running in the same logic as it stops, but first needs to clean merging area with occupied parcels. For cleaning parcels from merge area.

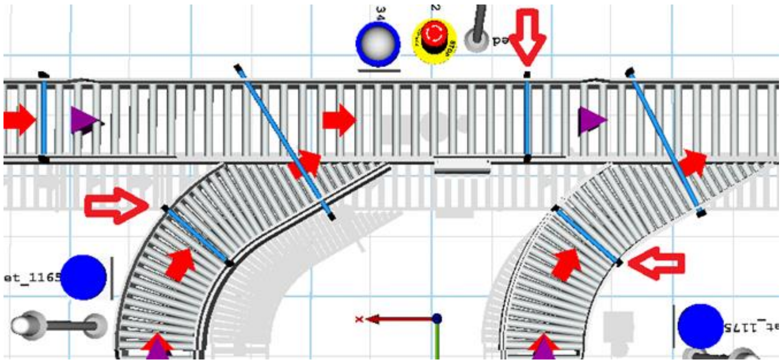


Fig. 22. Parcel location sensors

Sensors shown in fig. 23 is main sensors for merging area fault/collision detection. When on conveyor we have parcel collision for described time these sensors detect it and stop conveyors until manually parcels replaced from conveyor and pushed reset button.

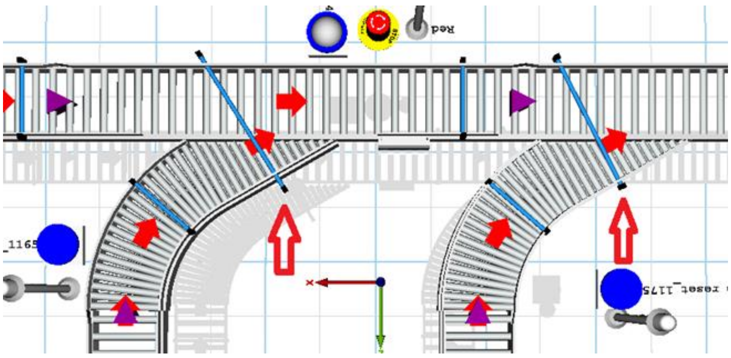


Fig. 23. Jam/ Collision sensors

4. Algorithm analysis and development

For main merging function in logic is used standardised alternate block which works with first in first out (FIFO) methodology Current FIFO method is working as main logic for merge areas – in any line delivered parcels occupies light check barrier for merge waiting request point and send signal that it is ready to hand over delivery to merge area. If at that moment there is any other deliveries, there is set in alternate block function how long other line should wait until release of parcels. Each line have different parameters of delay next light check discharge, because lengths and conveyor connections is at different place. If any of lines is empty it is skipped and system is working with lines where deliveries are. By literature sources best results are achieved with low burst time parameters. Varying with time and number of parcels parameters in this block, analysis was conducted.

In steady state flow the KDR sections on the main line will turn constantly when there is no downstream dieback or faults. The merge is operating in the following way:

- With programming logic controller there is opportunity to change parameters of running conveyors.
- With these possibilities of control merge flow there was used alternate block in Step7 software.

Bellow in figure is shown function block and in the tables described functions.

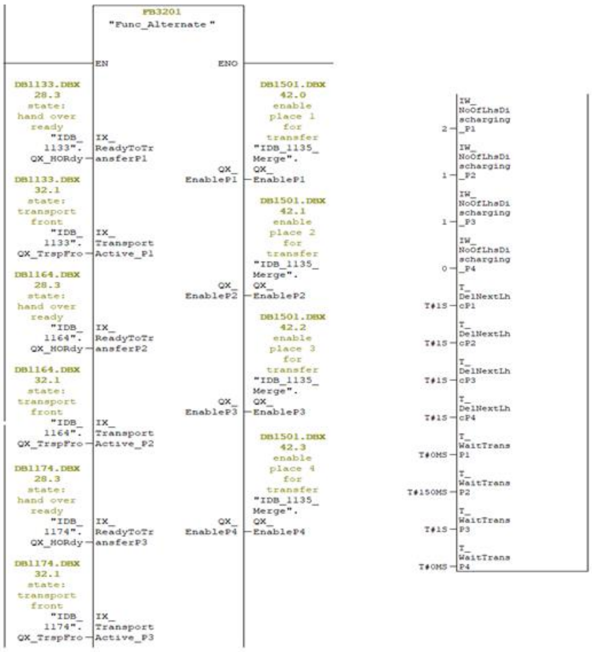


Fig. 24. Alternate block

Table 3. In/Out Interface

IX_ReadyToTransfer	Ready To Transfer
QX_Enable	Enable

Table 4. Module configuration

EnableTimeContr	FALSE	Enable Time Control
TransportActiveStop	FALSE	Transport Active Stop
EnableWaitingTime	FALSE	Enable Waiting Time

Table 5. Parameters

NoOfLhsDischarging	1	Number of Lhs Discharging
DelNextLhc	T#3S	Time Del Next Lhc
WaitTrans	T#1s	timer off delay Transport

For this type of analysis need to find required information of time variables which is used in software model to get system working.

4.1. FIFO method analysis

Logic basis starts from request point sensor for infeeds. If parcel is at request point, it sends signal that system are ready to send infeed to merge line. Calculation of time gap required for infeed parcels to merge is defined as time gap when parcel from main line passes through request sensor for infeeds until next parcel is detected on this sensor. When empty gap from main line is equal or higher of parcel size than to required time to merge it allows to spread parcel from infeed line.

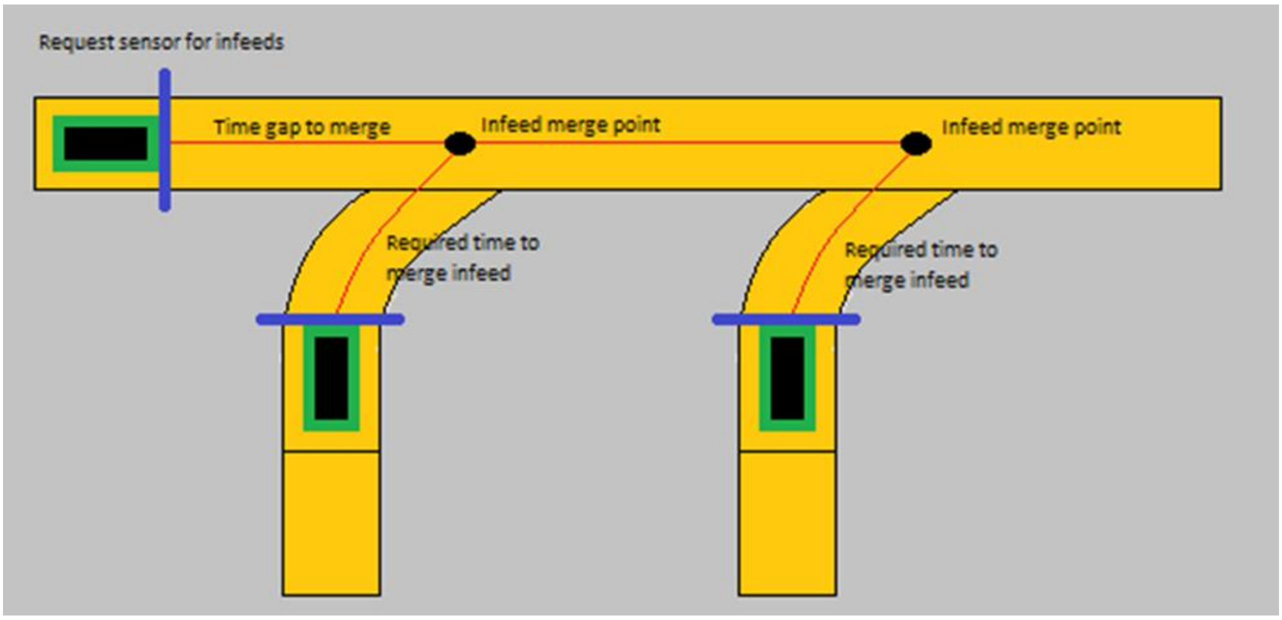


Fig. 25. Merge area with main points

To find optimal gaps in merge area requires to know how long it takes from each line to reach merge point. From SAL technical drawing can be measured distance from required to merge point to merge point:

From technical drawing is measured distances to merge points:

- First infeed to merge point – 2.15 m
- Second Infeed to merge point – 2.15 m

- Main line to first infeed merge point – 2.3 m
- Main line to second infeed merge point – 4.3 m

System variables:

$$v_{conveyor}: 1m/s \tag{13}$$

$$a_{conveyor}: 2{,}5m/s^2 \tag{14}$$

With collected data can be calculated parameters when from one line are spread parcel can be spread from another.

First needs to calculate required time for accelerate the conveyor:

$$t = \frac{v - u}{a} \tag{15}$$

$$t = 0{,}4s \tag{16}$$

When time parameter is known then can be measured distance how far it goes until achieves $v_{conveyor}$:

$$s = ut + \frac{1}{2}at^2 \tag{17}$$

$$s_{acceleration} = 0{,}2m \tag{18}$$

When is known how long and how far it goes when accelerating, needs to know how long it takes when speed is achieve to overcome the distance to merge point:

$$\frac{1}{2}at^2 + ut - s = 0 \tag{19}$$

$$t_{infeed1} = 1.95\ s \tag{20}$$

$$t_{maxinline} = 2.1\ s \tag{21}$$

The difference between main line and merge line is 0.15s. When main line spreads all required totes need to set 0.15s delay for infeeds to merge lines without collision.

With collected data, prepared emulation model and software with alternate block analysis were obtained with current FIFO method. Current FIFO method is working as main logic for merge areas – in any line delivered parcels occupies light check barrier for merge waiting request point by sending signal that it is ready to hand over delivery in to merge area. If front merge area are empty, then this line will start move forward, but if at that moment there is any other deliveries, line will stop at merge space request point and wait for time period which is set in alternate block function how long line should wait until release of parcels. Each line have different parameters of delay next light check discharge, because lengths and conveyor connections is at different place. If any of lines is empty it is skipped and system is working with lines where deliveries are.

Algorithm for FIFO method:

- Repeat Forever.
- Wait for signal ReadyToTransfer from Merge Space request sensor.
- If parcel is occupied the Space request sensor and sends ReadyToTransfer signal.
- Then send signal that conveyor is ready to hand over parcel.
- If line in front have place for parcels.
- Then send signal that hand over is ready.
- If hand over and take over is ready.
- Then release cycle after set time of DelNextLhc.
- If time gaps between spread parcels are higher than set value of WaitTrans.
- Then start cycle from other line.
- If other lines are waiting to be merged.
- Then finish cycle by counting amount of NoOfLhsDischarging set for cycle.
- If there are no parcels in other lines, flow will continue.
- If there are no parcels.
- Then stop conveyors.

Analysis with existing FIFO method was conducted. Main line are more loaded than infeed lines and throughput should be higher. With set flow of 4 parcels from main line and 2 parcels from each infeed parcels to deliver from each line with conveyor speed of 1 m/s. With FIFO method achieved result of 72 parcels per hour. Low space utilization is affected by before merge area connected accumulation conveyors, which have windows of 770mm for each parcel with different sizes of parcels. By this is affected space utilization with empty gap space between spread deliveries.

Fig. 26. Gaps between accumulation zones with parcels

4.2. Development of algorithm with fixed gaps for infeed lines

From conducted analysis of FIFO method can be seen that empty space gaps left after lines are merged together. To improve system throughput and use empty space on merge, new PLC logic will be used. For merge area will be set priority flow from main line and parcels from infeed lines will be spread in to gaps which are wide enough to implement them. The infeed conveyors will merge into the main conveyor line which has a priority flow.

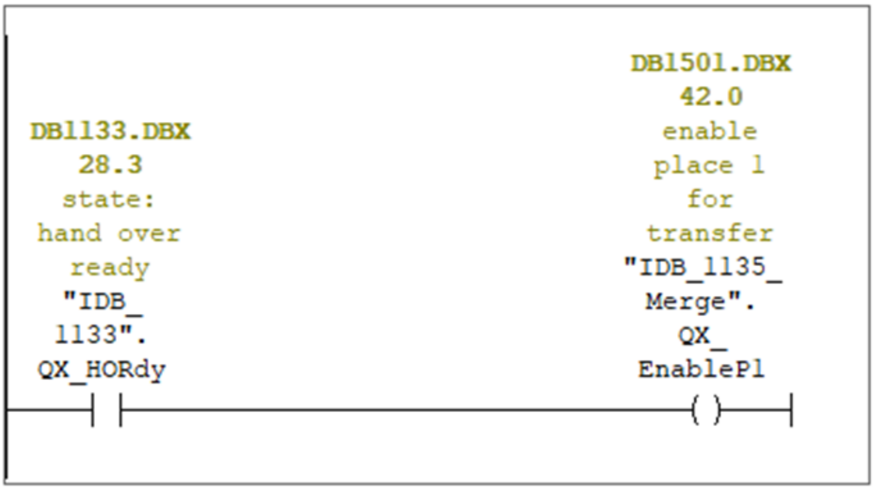


Fig. 27. Set flow for main line logic

Parcels length vary from 228 to 600mm in that case flow in main line are created with different size of free gaps space up to 372mm which can be filled with parcels from infeed lines. Maximum cartoon box size can be 520mm and tote size 600mm and possible empty gap on accumulation zone can be up to 542mm length. From that can be concluded that not all parcels can be filled in gaps on main line and additional logic will be needed to increase gap size that parcels longer than 542 could be filled as well.

For this improvement in conveyor software instance data block is used TiOffWait parameter, which have function of holding the transport and wait for requested time and then release it. Required gap size is 600mm. Deliveries on conveyors not all the time are placed correctly and can be rotated. It is affecting systems performance by create a collision between connected lines. To avoid this problem gap size is increased by 50mm what leads to more stable system performance. If gap time parameter between parcels is same or higher than set TiOffWait parameter, then main line is working without interruptions.

When parcel on main line goes across sensor before merge space request point sensor the free space gap is created.

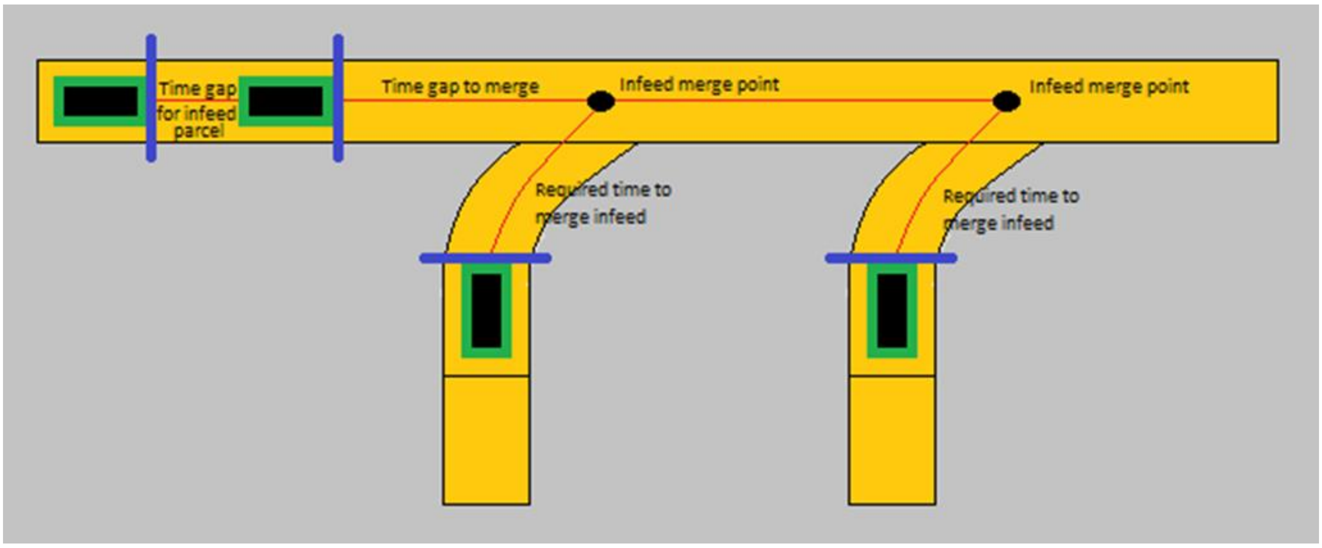


Fig. 28. Gap creation on merge area

When parcel on main line goes across sensor before merge space request point sensor need to create additional logic for releasing infeed line. Distances between main line and infeed line connecting points. Main line is longer than first infeed lines by 150mm. With additional 50mm for stable system waiting time is set 200ms.

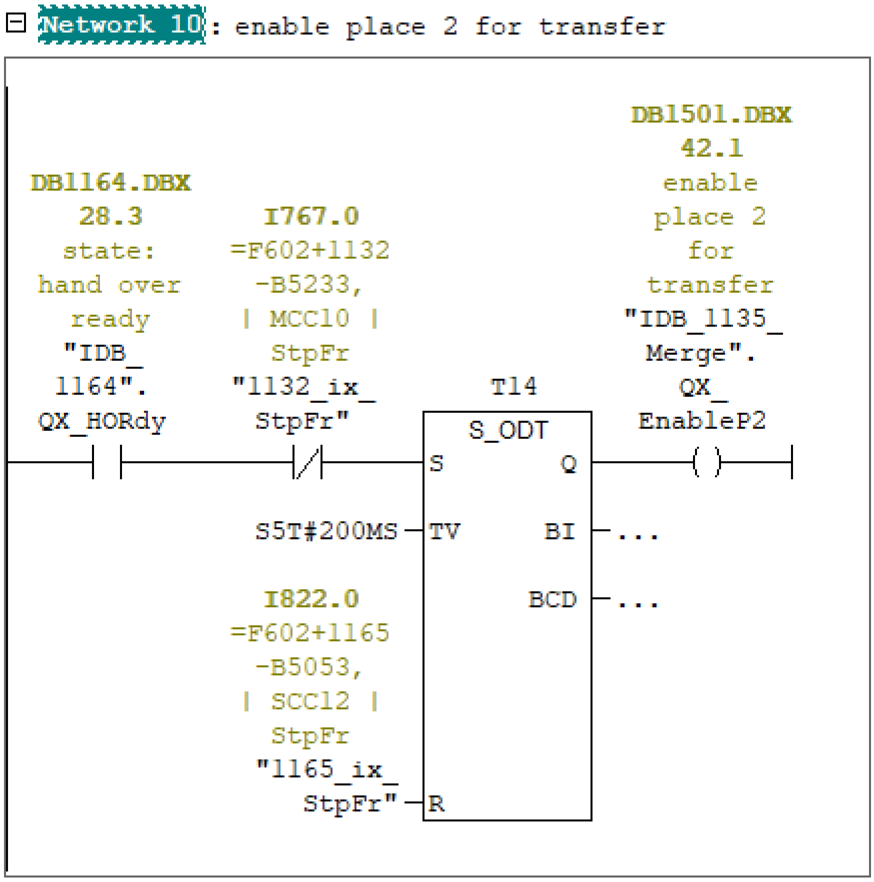


Fig. 29. Enable place 2 for transfer logic

Once a space becomes available on the main line, the system will transfer a parcel across and the normal accumulation sequence will continue. Main line will have a constant flow and for infeed lines will be created available space gaps of maximum parcel size on main line to fill free space on merge area. Infeed lines are working with FIFO function.

Algorithm for new method for merge area with priority flow from main line and fixed gaps for infeeds:

- Wait for signal ReadyToTransfer from main line merge space request sensor.
- If parcel is occupied the Space request sensor and sends ReadyToTransfer signal.
- Then send signal that conveyor is ready to hand over parcel.
- If line in front have place for parcels.
- Then send signal that hand over is ready.
- If hand over and take over is ready.
- Then release flow from main line.
- REPEAT
- If there are parcels on infeed lines on merge space request sensor.
- Send signal that hand over is ready.

- If time gap between parcels from main line are the same or higher than set time gap for infeed parcel.
- Then release infeed line.
- If not - hold transport to stop main line flow to create required gap for infeed.
- After requested time to wait, resume main line flow.
- If time gap between parcels from main line are the same or higher than set time gap for infeed parcel.
- Then release infeed line.

With this method system achieved 79 parcels per minute rate. Merge space utilization is not achieving best occupancy of the merge area because tote size cannot be found of running and stopping conveyor sections. From parcel flow can be found length of parcels by detecting for how long time sensor is occupied. But conveyor system not always have constant flow in which case measure parcels length cannot be done.

4.3. Development of algorithm with dynamic gaps for infeed lines

When infeeds are spreading parcels with fixed gaps, space is lost of varying length of parcels. To reduce gaps on main line parcel length needs to be known. It can be done by upgrading hardware configuration and implementing additional sensors on infeeds last section to measure parcel size. Dynamic gaps are created for different size of parcels by implementing additional sensors. First sensor have the same functions for conveyor section transport and communication control. For merge space request point in infeed lines is added sensors to create measurement for length. Parcel size difference varying from 228 to 600mm. Difference of parcels can be up to 372mm. With additional sensors length can be detected more accurate and occupancy of merge area conveyor section used more better.

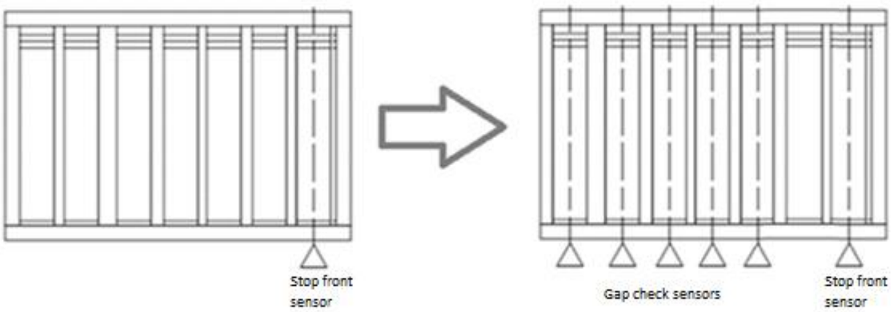


Fig. 30. Improved infeed hardware configuration

For dynamic gaps there is no parameters in conveyor blocks and for creating required gaps need to create logic for it. For main line in logic is set a priority flow as in method with constant flow from main line and fixed gaps from infeeds. For dynamic gapping first is implemented additional sensors and described what conditions will activate required gap for infeed parcel. It is done by occupying required amount of sensors as it is shown in picture bellow:

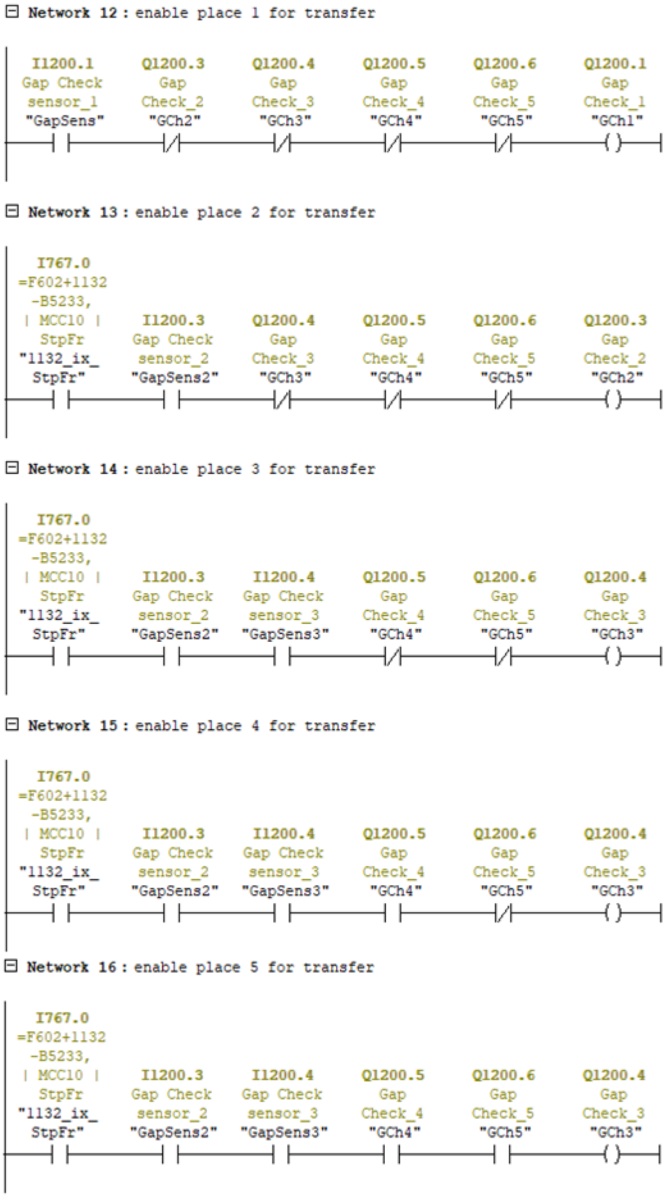


Fig. 31. Measured parcel logic

For example enable place 2 for transfer is activated when on last infeed conveyor section will be parcel length up to 290mm. In that case only stop front sensor is occupied and sends signal for shortest parcel condition. Another range of parcels working in the same manner. Bellow in table is shown what distance are between stop front sensor and additional sensors, measured gaps and required time to merge:

Table 6. Parameters for additional sensors

Description	Distance from Stop Front sensor, mm	Measured gap, mm	Required time to merge, ms
Stop front sensor	-	228-289	289
1 additional sensor	290	290 – 351	351
2 additional sensor	352	352 – 413	413
3 additional sensor	414	414 – 475	475
4 additional sensor	476	476 – 537	537
5 additional sensor	538	538 – 600	600

When parcel length is known additional logic for creating gap is required. In method with constant flow from main line and fixed gaps was used TiOffWait value from transport conveyor instance data block. To create dynamic gaps the same method cannot be used, because different values should be addressed to this function. Logic for dynamic gap creation starts by getting information from infeed line – handover is ready and what length of parcel is placed. When information from infeed lines is true and in main line flow parcel goes across stop front sensor then is activated merge area main line last conveyor section instance data block TiOffWait signal. It will be active until reaches required amount of time set for timer. To reset timer used logic when infeed spreads parcel and midpoint sensor of infeed is activated – timer is reset.

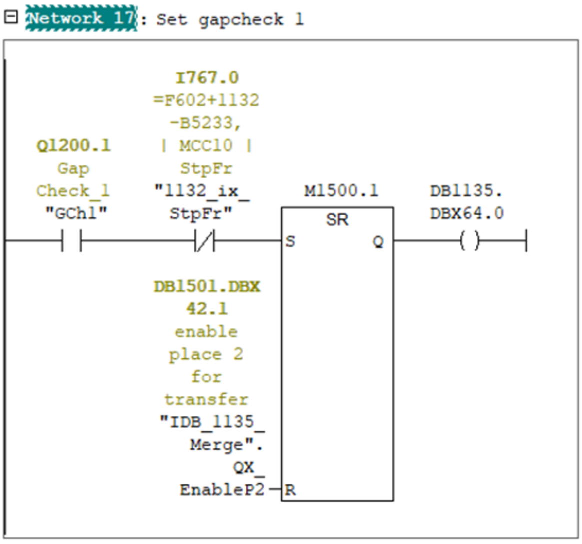


Fig. 32. Create first gap logic

To reset timer used logic when infeed spreads parcel and midpoint sensor of infeed is activated – timer is reset.

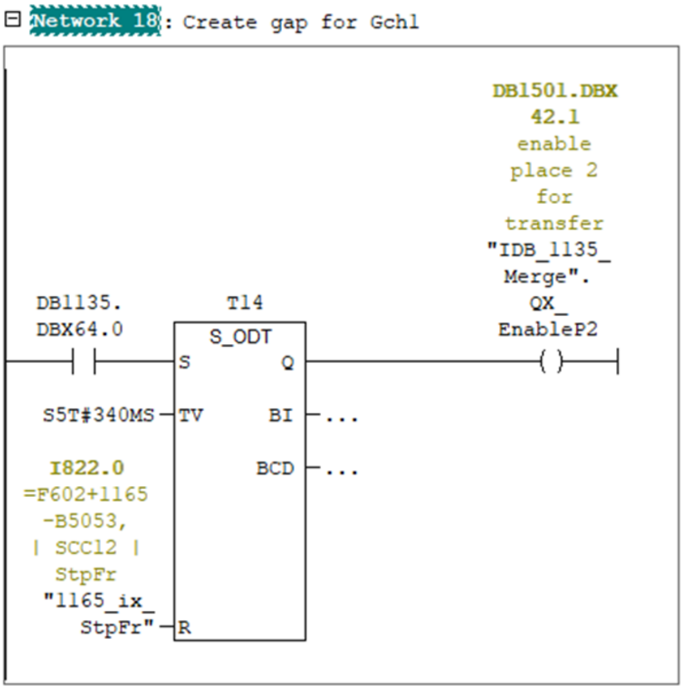


Fig. 33. Reset timer logic

When gap is created and parcel reaches main line merge stop front sensor it is spread with FIFO method. For method with variable gaps for infeed logic works in this way:

- Wait for signal ReadyToTransfer from main line merge space request sensor.
- If parcel is occupied the Space request sensor and sends ReadyToTransfer signal.
- Then send signal that conveyor is ready to hand over parcel.
- If line in front have place for parcels.
- Then send signal that hand over is ready.
- If hand over and take over is ready.

- Then release flow from main line.
- REPEAT
- If there are parcels on both infeed lines on merge space request sensors.
- Send signal that hand over is ready on both conveyor.
- Check how many sensors on last infeed conveyor section are occupied.
- Check if set time for occupied sensors by parcel is in limit of empty gap conveyor zone on main line.
- Compare infeed parcel lengths.
- If parcel size fits in the gap on main line.
- Then start infeed to insert parcel.
- If not then stop main line by creating required time gap for infeed line.
- Then start infeed to insert parcel.

With dynamic gaps system achieved 88 parcels per minute rate. It showed that with hardware improvement and creating gaps required for infeed parcels merge zone space utilization is improved by 16%.

5. Experimental results

To find required parameters for analysis were used Siemens Step7 programming software with SIMATIC S7-300 programmable logic controller (PLC) and Xcelgo Experior 6.0 emulation software for conveyor which allows to work with real time system with exact parameters used in PLC. Emulation are conceived to help with presenting initial solutions, simulating product throughput, system operation, and carrying out detailed control of the system [6]. Once the model has been constructed and the logical flow of parts through it has been created, it is ready to be used for analysis of both methods.

To start modelling in the beginning need to prepare software for conveyor running mode. There is several parameters which should be decided when conveyor is running, when it needs to stop, when it can spread parcels to next conveyor. For these parameters is used logic in Step 7 PLC program.

All development projects pass through the broadly recognized stages of an initial research among many possibilities, then a distillation down to a few reasonable ones, and then the selection of a preferred solution, and finally its implementation. Passing from one stage to the next in this process requires different levels of model detail.

Emulation are conceived to help with presenting initial solutions, simulating product throughput and system operation, and carrying out detailed controls testing.

- Developing and presenting initial solutions.
- Throughput analysis, system operation and improvement.
- Controls testing and virtual commissioning.

Once the model has been generated and software prepared it is ready to be used for analysis purposes. Advantage is the possibility to test different situations. PLC emulation means that all mechanical and electrical details are implemented in a 3D model and the original PLC code is running on a real PLC. Emulation model was created for existing merge area where is one merge line with two infeeds.

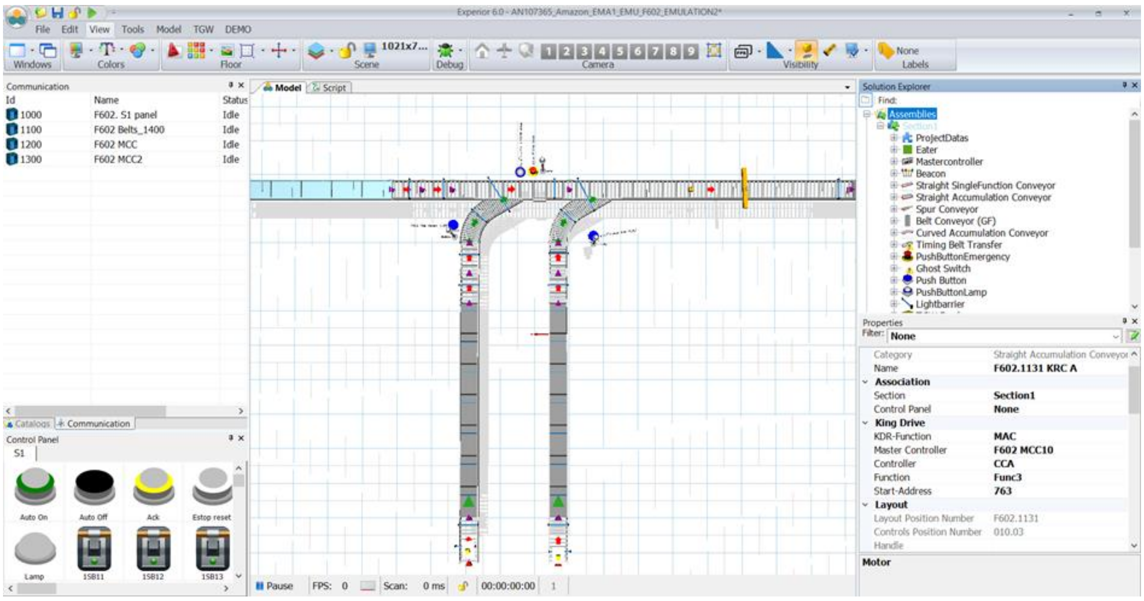


Fig. 34. Experior 6.0 Main dialog window

First was tested existing alternate block – first in first out. With conveyor speed of 1 m/s, set amount of spread parcels in one row – from main line – 4, infeeds - 2.With these parameters result was achieved of merge area utilization – 72 parcels per hour by total throughput of 4320 parcels per hour and fully balanced system. Low space utilization is affected by different sizes of parcels and gaps between them. Before merge area are connected accumulation conveyors, which have windows of 770mm for each parcel. When deliveries are sent in required amount there occurs large empty gaps between them. When from each line are spread group of parcels then gaps are variable size and in them could fit another deliveries. With FIFO method the result was reached by 72% of space utilization and 100% in balance of the system in merge area.

To improve system the new algorithm was created for merge area. In this method the infeed conveyors will merge into the main conveyor line which has a priority flow. Parcels length vary from 228 to 600mm in that case flow in main line are created with different size of free gap space up to 542mm which can be filled with parcels from infeed lines. Maximum cartoon box size can be 520mm and tote size 600mm from that can be concluded that not all parcels can be filled in gaps on main line and additional logic will be needed to increase gap size. When parcel on main line goes through merge space request point the free space gap is measured until next arriving parcel reaches the sensor. If measured gap have time parameter in which can be filled delivery from infeed than line is working without any corrections, but if gap is smaller and delivery can't be filled from infeed to merge area then gap is created by stopping main line flow for required time to create gap for parcel from infeed.

With implemented new method result of 79 parcels per minute which is 79% of space utilization and balance in the system was stable as well.

Third method for merge area was tested with priority flow from main line and spread parcels to gaps wide enough for parcels. Parcels length vary from 228 to 600mm and for small parcels utilize empty space is more reliable than do it for large parcels. This method is based on merge line priority with dynamic gaps created for infeed parcels. To create system which can work with dynamic gaps was done improvement in hardware configuration by adding additional sensors to measure parcel size more accurate. Range of measuring parcel was set to 68mm. With this type of range result was achieved by 88 parcels per minute on merge area.

Table 7. Achieved results of all methods

Description	FIFO	Fixed Gaps	Dynamic Gaps
Infeed 2, parcels per hour	18	19	22
Infeed 1, parcels per hour	18	20	22
Main Line, parcels per hour	36	40	44
Total, parcels per hour	72	79	88

From simulation based experimental analysis of conveyor merge area were performed three types of methods for conveyor logic control. By comparing results of all methods can conclude that throughput in merge area has been improved by 16% and system balance remained the same. When hourly rate in logistic centres are thousands of deliveries per hour, achieved 7% improvement in merge area system performance can be well used to increase whole warehouse performance. In fig. 35 can be seen that both methods are better than existing FIFO method. Main difference between new methods that for fixed gaps need changes only in software and for dynamic gaps need improvement in hardware configuration.

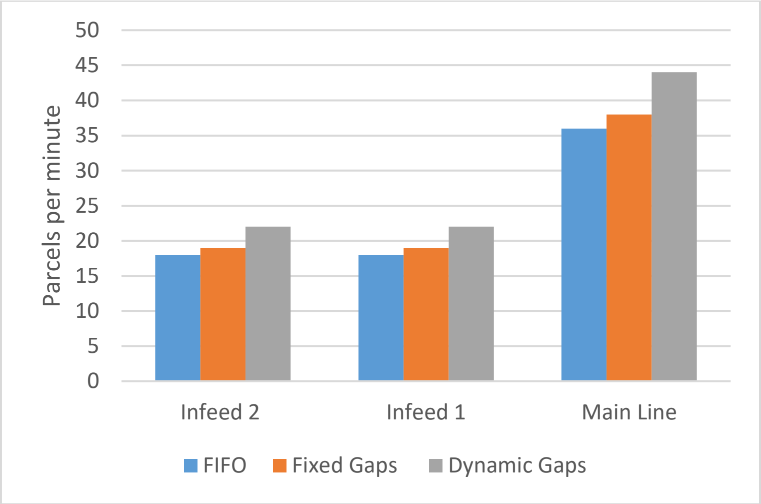


Fig. 35. Algorithm comparison diagram

6. Economical side of analysis

While conveyor warehouse systems becomes more complex, it is important to find better solutions for system and optimize process structure. To make process more efficient it was decided to investigate possibilities of merge operation with different algorithm logics by improving system space utilization, what increases performance.

For implementing method with fixed gaps on site it is cost effective, because commissioning engineers are implementing software on site and it need to be tested. To implement FIFO or method with fixed gaps it will take the same time and amount of investment.

Method with dynamic gaps have different situation, because there are needed to implement 5 additional sensors whose hardware costs are described in table 8 below:

Table 8. Cost of hardware

Description	Amount	Cost, Eur
Photoelectric sensor with reflector	5	50
Cables	5	2
Case for sensor and reflector	5	30
Total		410

First need to prepare project for implementing update to existing system. It takes about one day to prepare technical project to be analysed. After technical project is accepted, need to prepare all technical documentation which consists of several different type of data: electrical drawings, layout drawings, specific conveyor design layouts. Time required for implementation of new hardware needs about two days, because it needs to be implemented and aligned to perform correctly. This sum of all steps for employee work can be different if there is need to travel abroad and do all changes. Then occurs travel costs and price is increased. Employee cost is calculated on hourly rate when average engineer hourly rate is 6.25 Eur.

Table 9. Employee cost

Description	Required time, h	Average day pay, Eur	Cost, Eur
Technical task	16	50	100
Technical project preparation	8	50	50
Technical Drawings	8	50	50
Total	32	-	200

Final cost consist of hardware cost and employee time cost for implementing new configurations which at total reaches 610 Eur.

Table 10. Total cost

Description	Cost, Eur
Hardware cost	410
Employee cost	200
Total	610

With FIFO method is achieved 4320 parcel per hour rate and comparing it with other two methods, with fixed gaps method is achieved 420 parcels per hour better performance and with dynamic gaps – 960 parcels per hour. It is large numbers in warehouse distribution centres. With achieved result system can perform tasks faster and save money in operating time or produce more work in the same time. For customer it is high value by removing or reducing delays and improving response time and to maximize utilization and minimizing down time.

7. Recommendations and further study

By applying new algorithms it could be next step for standardisation of new methods as it is done for FIFO method. By creating function block and minimalizing logic parameters required to set for different design of conveyor merge zones. To analyse whole system performance and see how new implemented flow is working in the system, simulation can be done. With simulation model can identify problems occurring in change of different flows where are generated mathematical model [21].

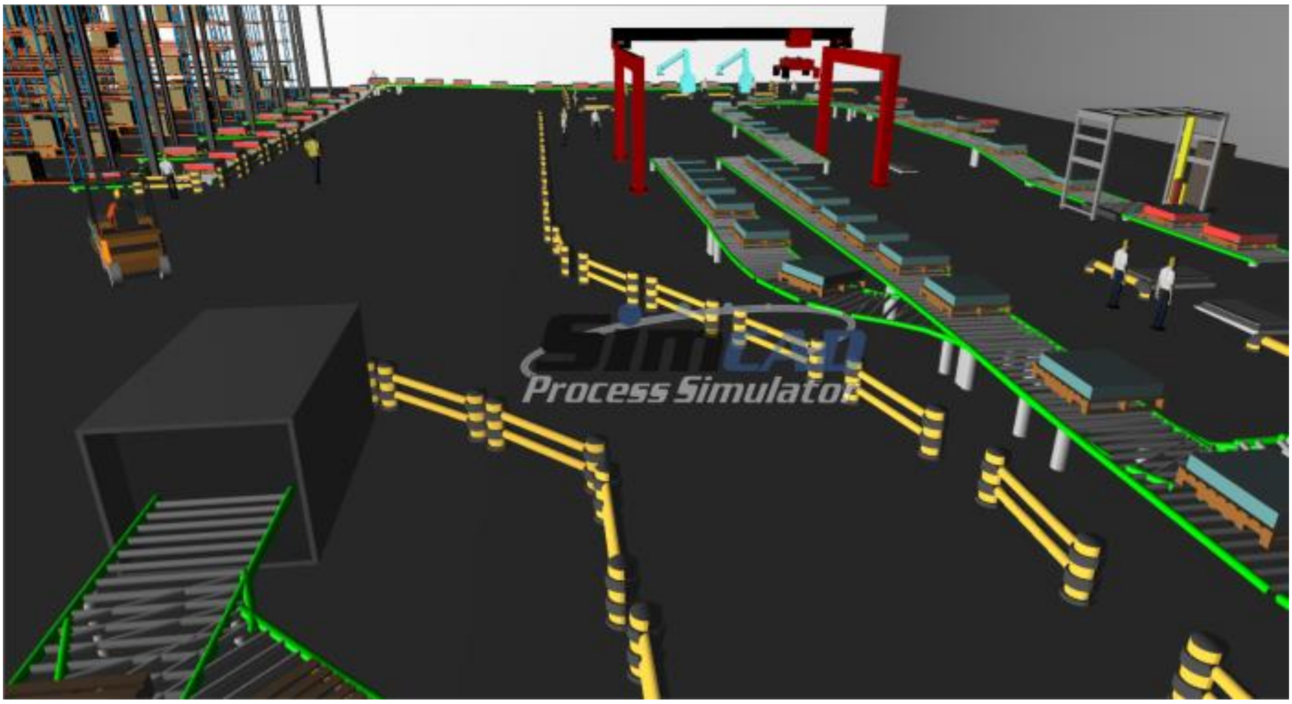


Fig. 36. Simulation model [22]

In this case was analysed one of main points in conveyor warehouse structure, but there is more complicated spots which can be analysed and tested for reaching better performance such as sorter conveyor, slug belt merge conveyor, pop up conveyors, diverts. Each zone can by analysed to know if there are achieved best result and what improvement can be done.

Conclusions

1. Analysys of warehouse structure was conducted to understand working principle of conveyor system
2. Analysed methods for merge model. From all these methods can be seen that main function is to reach better throughput and have minimized imbalance in the system. Any method is good and applicable in certain circumstances. The Priority based method could be used for any amount of infeed lines, because there is the same logic which repeats for each line. The first come first out method could be achieved best results with low burst time value processes, shortest job first method best conditions would be to work when processes came at the same time. Round robin method should be used when needed accommodation for average is waiting. Other source says that EDF have better parameters when system is with low flow than ACO, otherwise EDF is not such good as ACO or genetic based algorithm when system is highly loaded. Not all of these methods can be applicable in this case, because merge area is one point of the system and for other methods should be done route analysis and more parameters needs to be given. For this analysis was decided to anlyse method with constant flow from main line and spread parcels from infeed lines with FIFO method.
3. Designed two new logical structures for merge area. First method was designed with constant flow from main line and created fixed gaps on main line for infeed parcels. For this method changes was done only in software logic. Other method is designed with constant flow from main line and dynamic gaps for infeed parcels. With this method gaps on main line are created required size for parcel length on infeed line. To create dynamic gaps were done changes in software logic and hardware configuration, by adding additional sensors for measuring parcel.
4. Emulation model was created with connected programming logical controller and tested existing FIFO method and new generated methods: with constant flow from main line and fixed gaps for implement parcels from infeeds to main line and method with dynamic gaps. With emulation model was analysed existing method, developed and tested new methods for operating mode.
5. In this study was analysed and developed conveyor warehouse merge operating area and improved working methods. By analysing existing FIFO method was achieved 72 parcels per minute rate, with new created method with fixed gaps – 79 parcels per minute and with new method with dynamic gaps – 88 parcels per minute. From this analysis can be seen that system performance was achieved with both new designed algorithms. With fixed gaps system performance increased by 7% and with dynamic gaps by 16%.

List of references

1. FEDTKE S.; BOYSEN N. Layout planning of sortation conveyors in parcel distribution centers [interactive]. [Jena, Germany]: Friedrich-Schiller-Universität Jena, 2012 September [accessed 2018 03 20]. Internet access:
   <https://pdfs.semanticscholar.org/665f/c8235ca871926eb5d61471cba2462cc540c2.pdf> .
2. ZAJAC P. Evaluation Method of Energy Consumption in Logistic Warehouse System [interactive]. [Wroclaw, Poland]: Wroclaw University of Technology, 2015 [accessed 2018 03 20]. Internet access:
   <https://books.google.lt/books?id=X4uQCgAAQBAJ&pg=PA157&lpg=PA157&dq=2.+ZAJAC,+P.+Evaluation+Method+of+Energy+Consumption+in+Logistic+Warehouse+System&source=bl&ots=0PBSi-yun1&sig=VoJOWC9lTNrAUnqSqSSdB78tMV0&hl=lt&sa=X&ved=0ahUKEwiZkb-JlJ_bAhXFBZoKHdZ2A6EQ6AEIRzAH#v=onepage&q=2.%20ZAJAC%2C%20P.%20Evaluation%20Method%20of%20Energy%20Consumption%20in%20Logistic%20Warehouse%20System&f=false> .
3. TOMPKINS J.A.; HERMELINK D. D. The Supply Chain Handbook [interactive]. [Coventry, United Kingdom]: Tompkins Press, 2004 [accessed 2018 03 20]. Internet accessed:
   <https://books.google.lt/books?id=BKXOYgh9UPcC&printsec=frontcover&hl=lt&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false> .
4. DOLGUI A.; PROTH J.M. Supply Chain Engineering [interactive]. [Saint-Etienne, France]: Centre for Industrial Engineering and Computer Science, 2010 [accessed 2018 03 22]. Internet access:
   <https://books.google.co.uk/books?id=A8QzC6wEKsC&pg=PA424&dq=supply+chain+conveyors&hl=lt&sa=X&ved=0ahUKEwiF5ZeXyp3aAhWmQpoKHdv6A84Q6AEIMTAB#v=onepage&q=supply%20chain%20conveyors&f=false>
5. GARCIA M. I., Layout planning of Continuous Conveyor Systems Using Modelica [interactive]. [Graz, Austria]. Graz University of Technology, 2017 [accessed 2019 03 23]. Internet access: <http://diglib.tugraz.at/download.php?id=5a1defd9ae522&location=aleph>
6. COYLE J. J., LANGLEY C. J., GIBSON B. J., NOVACK R. A., BARDI E. A. Supply Chain Management [interactive]. [Mason, USA]: South-Western Cengage Academic Resource Centre, 2009 [accessed 2018 03 22]. Internet access:
   <https://books.google.co.uk/books?id=TbuZnzcXGysC&pg=PA504&dq=supply+chain+conveyors&hl=lt&sa=X&ved=0ahUKEwiF5ZeXyp3aAhWmQpoKHdv6A84Q6AEIOjAC#v=onepage&q=supply%20chain%20conveyors&f=false>
7. MCGUIRE P. M. Conveyors Application, Selection, and Integration [interactive]. [New York, USA]: Taylor & Francis Group, 2009 [accessed 2018 03 22]. Internet access:
   <https://books.google.co.uk/books?id=558l93ERNU4C&printsec=frontcover&dq=conveyors&hl=lt&sa=X&ved=0ahUKEwik5_bfyp3aAhVJyKYKHZKOCG8Q6AEIKDAA#v=onepage&q=conveyors&f=false>
8. SENANI R., BHASKAR D. R., SINGH A. K. Current Conveyors [interactive]. [New Delhi, India]: Sharda University, 2015 [accessed 2018 03 24]. Internet access:

<https://books.google.co.uk/books?id=YFHFBAAAQBAJ&pg=PR11&dq=conveyors&hl=lt&sa=X&ved=0ahUKEwi28oaGy53aAhWLJ5oKHcTNCKA4ChDoAQgnMAA#v=onepage&q=conveyors&f=false>

9. RUSHTON A., CROUCHER P., BAKER P. The Handbook of Logistics and Distribution Management [interactive]. [London, UK]: The chartered institute, 2010 [accessed 2018 03 24]. Internet access:
<http://s1.downloadmienphi.net/file/downloadfile7/149/1381418.pdf>
10. ROGERS K. L. Keep materials moving [interactive]. Modern Materials Handling, April 11 2011 edition [accessed 2019 01 24]. Internet access:
<https://www.mmh.com/images/site/MMH1104_EquipRpt_Conveyors.pdf>
11. LI J., BLUMENFELD E. D., HUANG N., ALDEN M. J. Throughput analysis of production systems: recent advances and future topics [interactive]. International Journal of Production Research, 2009. p. 3823 – 3851 [accessed 2019 02 22]. Internet access:
<https://www.researchgate.net/publication/228345203_Throughput_analysis_of_production_systems_Recent_advances_and_future_topics>
12. BLACK G., VYATKIN, V. Intelligent component-based automation of baggage handling systems with IEC 61499. [interactive]. [Auckland, New Zealand]: Article in IEEE Transactions on Automation Science and Engineering, 2010. p. 337 – 351 [accessed 2019 04 22]. Internet access:
<https://www.researchgate.net/publication/224369664_Intelligent_Component-Based_Automation_of_Baggage_Handling_Systems_With_IEC_61499>
13. GASPERIN S., JODIN D. Dynamic merge of discrete goods flow–Impact on throughput and efficiency [interactive] Internet Logistics Journal, 2012 [accessed 2019 04 23]. Internet access:
<https://graz.pure.elsevier.com/en/publications/dynamic-merge-of-discrete-goods-flow-impact-on-throughput-and-eff>
14. HANEYAH S. Generic control of material handling systems [interactive]. [Enschede, The Netherlands]: University of Twente, 2013 [accessed 2019 04 02]. Internet access:
<https://ris.utwente.nl/ws/portalfiles/portal/6060373/thesis_S_Haneyah.pdf>
15. SIAHAAN, A. P. U. Comparison analysis of CPU scheduling: FCFS, SJF and Round Robin [interactive]. [Sumatera Utara, Indonesia]: Universitas Pembangunan Panca Budi, International Journal of Engineering Development and Research, 2016. p. 124 – 132 [accessed 2019 03 11]. Internet access:
<https://www.ijedr.org/papers/IJEDR1603022.pdf>
16. SALAM A., ABBAS S., KHAN Y., HAQ S., JAN S. U. Developing the Best Scheduling Algorithm From Existing Algorithms for Real Time Operating Systems [interactive]. [Chakdara, Pakistan]: University of Malakand, 2019 [accessed 2019 03 09]. Internet access:
<https://www.researchgate.net/publication/331407449_Developing_the_Best_Scheduling_Algorithm_From_Existing_Algorithms_for_Real_Time_Operating_Systems>
17. GOEL A, SHARMA, G. Challenges in Scheduling in Operating System [interactive]. Bilingual International Conference on Information Technology: Yesterday, Today, and Tomorrow, 2015 [accessed 2019 02 05]. Internet access:
<https://www.researchgate.net/publication/273132329_Challenges_in_Scheduling_in_Operating_System>

18. JOHNSTONE M., CREIGHTON D., NAHAVANDI S. Simulation-based baggage handling system merge analysis. Simulation Modelling Practice and Theory [interactive]. [Victoria, Australia]: Centre for Intelligent Systems Research, Deakin University, 2015 [accessed 2018 04 02]. Internet access:

<https://www.sciencedirect.com/science/article/pii/S1569190X15000131>

19. JING, G. G., ARANTES, J. C., KELTON, W. D. Robust analysis via simulation for a merging-conveyor queueing model [interactive]. Proceedings of the 1998 Winter Simulation Conference, 1998 [accessed 2019 02 05]. Internet access:

<https://www.informs-sim.org/wsc98papers/142.PDF>

20. Conveyor & Sortation Technologies [interactive], [accessed 2018 04 19] Internet access:

< http://www.mhi.org/solutions-community/solutions-guide/conveyor>

21. HAFILAH D., RADJA A., RAVALONTSALAMA R. N., LAFDAIL Y. Modeling and Simulation of Baggage Handling System in A Large Airport [interactive].18th Asia Pacific Industrial Engineering and Management System Conference, 2018 [accessed 2019 02 05]. Internet access:

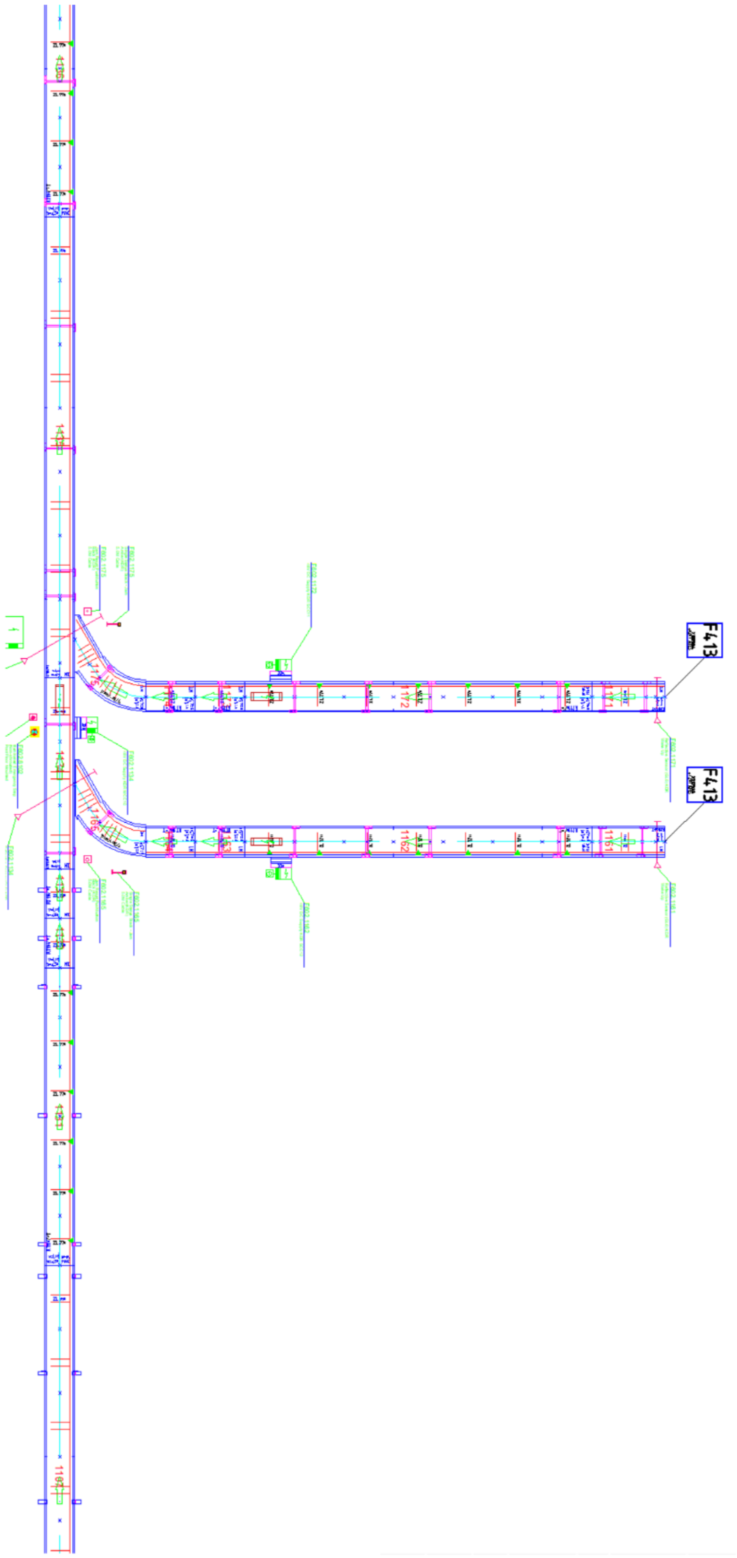
<https://hal.archives-ouvertes.fr/hal-01686750/document>

22. SIMCAD Conveyor Simulation: Predictive Modeling and Analytics [interactive], [accessed 2019 04 19] Internet access:

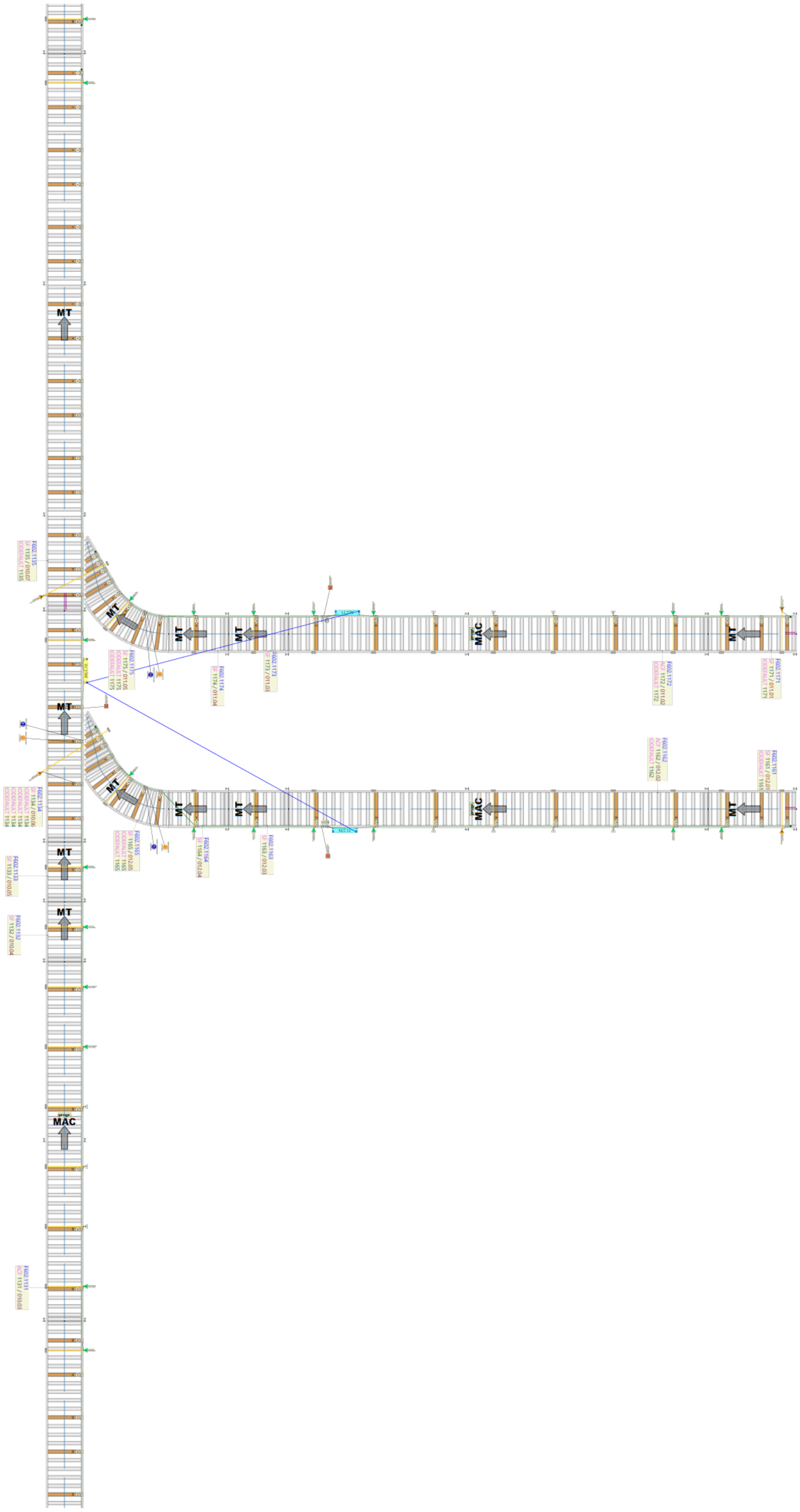
< https://www.createasoft.com/conveyor-simulation>

Appendices

SAL drawing of merge zone



Ktool drawing of merge zone:



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Automated Logistic Systems Conveyor Merge Zone Performance Research

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1. Introduction

Automated logistic warehouses is a large system where all parcels from arrival to departure point should be delivered in the shortest time. Transportation System is used to keep balanced number of deliveries variation between schedules and demand [1]. There are many variables, who determines result of fluent delivery time and to achieve it most complicated areas should be analysed and improved in the system. In this research is chosen to analyse conveyor merge area where several conveyors connect to one. This paper aim is literature review and compare of methods and performance comparison using emulation model with connected programmable logical controller. Research of throughput and workload balance optimization will lead to most efficient performance of merge area.

2. Merging area algorithms

In this case is analyzed three lines merge to one-line conveyor throughput efficiency and balancing the system, what methods is used and how it can be improved in existing system.

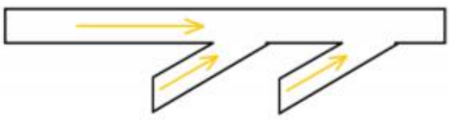

Fig. 1 Merge zone

Main line is horizontal line, from which parcels are coming from other areas and on the right side is connected two infeed, which used from another lines such as – packing, assembling or similar. To achieve best throughput, need to use method, which performs most utilization in merge area.

For merge area can be used static or dynamic approaches [2].

Static approach takes closer look at moment of merging area with parcels on lines and try to examine it. It can be used repetitive times with different amounts of parcels in merge area and different empty slots to be filled.

Static approach achieves 100% possible space utilization and balanced workload. Finding best result to achieve optimal solution with static method takes a lot of time and cannot be used in real time systems.

Dynamic approach is taking care of empty space on main when system is online, which is filled with deliveries from infeed lines. Possible deliveries to empty space on main line could be spread when meets the requirements for space window. In conveyor warehouses where main task is to achieve better throughput and not 100% in balance this approach is more suitable.

For dynamic approach is used main scheduling methods [3–5]:

First in first out (FIFO) method is defined as first parcel stands on a waiting point is spread first and only when all process is completed next process will be started.

Shortest job first (SJF) – stands on logic where shortest burst time will get a priority. This leads that more space left in the system and it possibly can be occupied by other jobs.

Round Robin method is based on set time parameter. If system variables satisfies the conditions it starts job and if job needs more time than set time, it is interrupted and other job gets time to perform. If sytem is highly loaded then algorithm becomes FIFO.

Earliest deadline first (EDF) – priority goes to that process which has closest deadline to be done. Parameters on which depends this method is such as fill level of each line, release time, when it started and when should be finished, accomplishment. This method has disadvantage for high volume processes

Ant colony optimization (ACO) – working as natural ants that each of them makes a trackway and all of them are an option at the same time. Separate ant represents her journey from various point of trackway and prioritized by importance and repetition of delivery.

Genetic algorithm based on repeat after generations same process again. By memorizing required information and keeping it until needed. This method learns from past actions and group similar parameter to make sure of future possible same processes and put in priority best process.

Adaptive method consists of earliest deadline first and ant colony optimization commonly used for improvement to balance the system. Logic of this algorithm is if lines are not loaded use EDF method prioritize processes by deadline and if flow of the system is high, then EDF is changed to ACO method and counting parameters of fastest process and implementation of whole processes at the time.

3. Analysis of working principles

System is designed for tote and case deliveries. Tote dimensions are fixed, but cases parameter can vary and depends from size of delivery. Conveyor speed is 1m/s and acceleration of conveyor is 2.5m/s. In case to reduce collisions and make system more reliable in faults, system accumulation conveyors have parcel windows length of 770 mm while maximum length of delivery is 600 mm. In perfect conditions conveyor with case size of 600 mm and 100%

perimental model was done with programmable logic controller Siemens SIMATIC S7-300 connected to PLC and used Siemens Step 7 software for programming and Experior software for emulating. With experimental equipment results were done analysis for both methods. For alternate FIFO method with set of finite number of spread parcels from each line – from main line – 4, infeeds – 2. With these parameters achieved result by 72 parcels per minute by total throughput of 4320 parcels per hour and fully balanced system, from this method can be seen that 71% of conveyor merge area is exhausted and still 29% of conveyor space is not utilized. With complex method of SJF and EDF method results was achieved by 87 parcels per minute rate and total 5220 parcels per hour and balance in system reduction through main and infeed lines.

	FIFO	Complex
Infeed 2	18	17
Infeed 1	18	19
Main Line	36	51

Fig. 5 FIFO and Complex SJF and EDF methods

From this data can conclude that throughput was improved by 15% in merge area by changing working method principle and improvement in hardware, but system balance decreased in this area in case of gap difference and spread amount of parcels from infeed lines.

With amount of thousands parcels per hour merge system improvement with complex SJF and EDF method leads to whole warehouse control system improvement and faster performance.

References

1. **Tompkins, J. A., & Harmelink, D. A. (Eds.).** 2004. The supply chain handbook. Tompkins Press. 478p., ISBN-10: 1930426038
2. **Haneyah, S., Hurink, J., Schutten, M., Zijm, H., & Schuur, P.** 2011. Planning and control of automated material handling systems: The merge module. In Operations Research Proceedings, pp. 281-286, Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-20009-0_45.
3. **Siahaan, A. P. U.** 2016. Comparison analysis of CPU scheduling: FCFS, SJF and Round Robin. International Journal of Engineering Development and Research 4(3): 124-132. https://doi.org/10.31227/osf.io/6dq3p.
4. **Salam, A., Abbas, S., Khan, Y., Haq, S., & Jan, S. U.** 2019. Developing the best scheduling algorithm from existing algorithms for real time operating systems. Available at SSRN 3331997 https://doi.org/10.13140/RG.2.1.1247.3686.
5. **Goel, A., Sharma, G.** 2015. Scheduling Challenges in Operating System. [online] [accessed 12 Febr. 2019]. Available from Internet https://www.researchgate.net/publication/273132329_Challenges_in_Scheduling_in_Operating_System/stats.
6. **Fedtke, S., Boysen, N.** 2014. Layout planning of sortation conveyors in parcel distribution centers. Transportation Science 51(1): 3-18. https://doi.org/10.1287/trsc.2014.0540.

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AUTOMATED LOGISTIC SYSTEMS CONVEYOR MERGE ZONE PERFORMANCE RESEARCH

S u m m a r y

The purpose if this study is to analyse one of main points in conveyor warehouse system – merge area. The aim of the work is to achieve better results in system throughput with appropriate balance of the system. In research is explained main methods for merging algorithms in dynamic and static approaches.

Once the methods were analyzed then existing FIFO model was compared with complex method consisting of shortest job first and earlies deadline first methods which are applied for real time conveyor system.

Results of the study showed improvement in the merge operating area throughput by using hardware improvement and complex method.

To achieve results simulation model was conducted with existing parameters and done with both method logics. The major conclusion to this study that with customized complex SJF and EDF method with hardware improvement results in throughput increased by 15% than with existing FIFO method.

Keywords: conveyor, warehouse, logistic, merge, alternate, system balance, system throughput

utilization should achieve 5454 deliveries per hour, but window size is increased by fixed gaps of 170mm to avoid collision in all routing processes and this leads to throughput of 4675 deliveries per hour. Making system reliable efficiency is affected and reduction of 16.6% in throughput, but stable system with less possibility to get fault in parcels collision.

Merge areas is designed in the last point just before sorter system. Sorter system speed is higher than all system and could be set up to 2.5 m/s. Before entering sorting area there is gaper belts, where required gaps is set for sortation. The gaps between parcels are checked and corrected if necessary by the dynamic gaping unit and diverted at the desired positions.

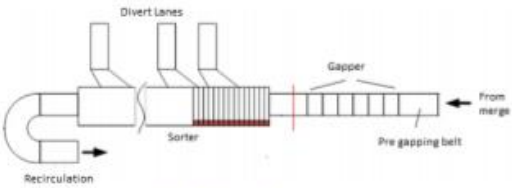

Fig. 2 Sorter Structure

That leads that before sorter area gaps between coming parcels can be reduced and increased throughput of the system.

In working merge operating mode conveyor infeed sections on the main line will turn constantly. The merge is operating in the following way:

• Arriving cartons will travel through the merge point if it is clear to do so.

• Once a slug is released the configured number will be passed through the merge. Once the number has passed through the other feed will be released for the configured number of cartons.

• The configured number can be different between feeds to prioritise one feed over the other.

• If no parcels have been arrived for a certain period across any of the infeed lines, then the control mode will skip it and will work with rest of lines.

Current FIFO method is working as main logic for merge areas – in any line delivered parcels occupies light check barrier for merge waiting request point and sends signal that it is ready to hand over delivery in to merge area. But if at that moment there is any other deliveries, there is set in alternate block function how long other line should wait until release of parcels. Each line has different parameters of delay next light check discharge, because lengths and conveyor connections is at different place. If any of lines is empty it is skipped and system is working with lines where are deliveries.

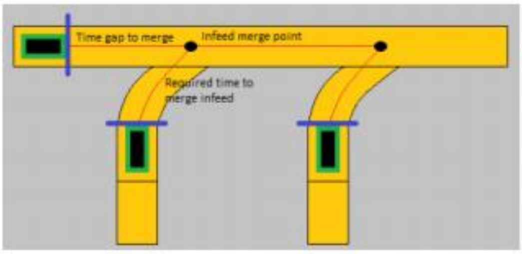

Fig. 3 Merge area time variable sand main points

Constant flow crosses the merge area with smallest gaps of 170 mm created by accumulation flow. When parcel sizes varying from 228 to 600 gap can reach size of 542 mm. In case that flow in the system can be delayed by high load, parcels can be delayed and gaps can reach higher sizes. In that case in one gap can be spread up to 2 parcels.

To improve system throughput another method for merge area was tested with priority flow from main line and spread parcels to gaps wide enough for parcels. Parcels length vary from 228 to 600mm and for small parcels utilize empty space is more reliable than do it for large parcels. This method is based on merge line priority with complex method consisted from shortest job first and earliest deadline first. And improvement in hardware by adding additional sensors to measure parcel size. As main line is set as priority line and just in gaps is spread parcels from infeed lines additional logic is set for infeed. One of main points in logic which is based on SJF method, that to main line will be spread smaller parcel in to gap in case that in the same gap could be filled one more parcel from other infeed. It will work in that manner until is reach another specification – If one of the system accumulation lines reaches required fill level, then this line is set to spread parcels more often than other. In case of both lines are full then it works by sending parcels one by one from each infeed.

Logic basis starts from request point sensor for infeeds. If parcel is at request point, it sends signal that system is ready to send infeed to merge line. Measuring and varying with time parameters for infeeds to merge main line can allocate space gaps and times when actions needs to be taken when all logic starts [6]. Calculation of time gap required for infeed parcels to merge is defined as time gap when parcel from main line passes through request sensor for infeed until next parcel is detect on this sensor. When empty gap from main line is equal or higher of parcel size then infeed is set to merge and allows to spread parcel from infeed line. Logic resets and start looking for place again when parcel is spread and reaches mid-range sensor.

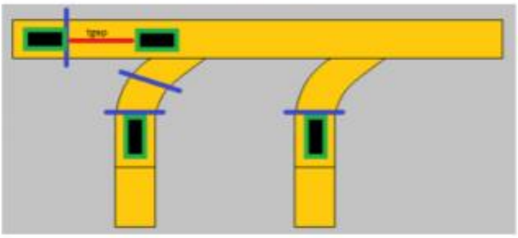

Fig. 4 Gap measurement

4. Results and conclusions

From this analysis was stepped closer at the existing space allocation problem in merge configuration, which is a local traffic problem that occurs in logistic sectors. Objective was to analyse different methods of space allocation. Not all methods can be applicable at exact situation due to one point analysis. Such for ant colony optimization or genetic algoritms should be used for alaysis of whole site. After analysed all methods was concluded that static approach is not common used for real time operating systems and decided to compare existing FIFO method with complex method of shortest job first and earliest deadline first. Ex-

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Automated warehouse conveyor systems merge operating area throughput and workload balance system research

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1. Introduction

Logistic Warehouses Transportation System is used to keep balanced number of deliveries variation between schedules and demand. To accumulate products from logistic faults of manufacture within firms for combined shipment to common customers, to shorten transportation distances and permit rapid response to customer demand. Nowadays logistic warehouses and distributions centres are created on the basis of different optimization decisions.

This article presents automated warehouse conveyor system structure of merge area analysis for throughput and workload balance in the system. There are analysed existing first in first out algorithm with created new method with priority flow from main line and created gaps for infeed conveyor. Designed merge area algorithms were analysed and done simulation model to measure performance changes in the system.

2. Merge area analysis

This research is done based on the merge area structure analysis and comparison of programming logical controller algorithms for performance analysis.

Warehouse Management Systems (WMS) became more important and complex, that causes quite hard to manage for consumers. The warehouse management systems are essence elements of the packages flow in logistic process and to optimize process structure [1]. The most efficiency of a logistic centres are achieved when customer gets what expects and are satisfied according to requirements he gave for project, with lowest cost and best performance.

For merge area are analysed roller conveyor sections, where can be accumulated packages for a determined amount of time until it needs to release in other segments of warehouse such as automated sorter or merge [2]. Motorized roller is also known as internal motor or motor driven roller conveyor. Motorized roller conveyor are divided into sections, where at least one roller are connected to motor which drives rollers. It is used be-cause of less energy consumption than different types of drive motors and provides less torque and in this way make it safer [3].

Merge area have main points where information are obtain and used in programming logical controller [4]. Merge space request point (Fig. 1) is the point at which parcels stop and wait for action to be taken in merge logic. As delivery reaches this point, system gets signal that parcel covered the sensor and it is ready to be merged. In connection of two conveyors there is sensor for collision detection. The last sensor on the merge area is merge point. It is straight after all infeed lines. This point means end point of merging area.

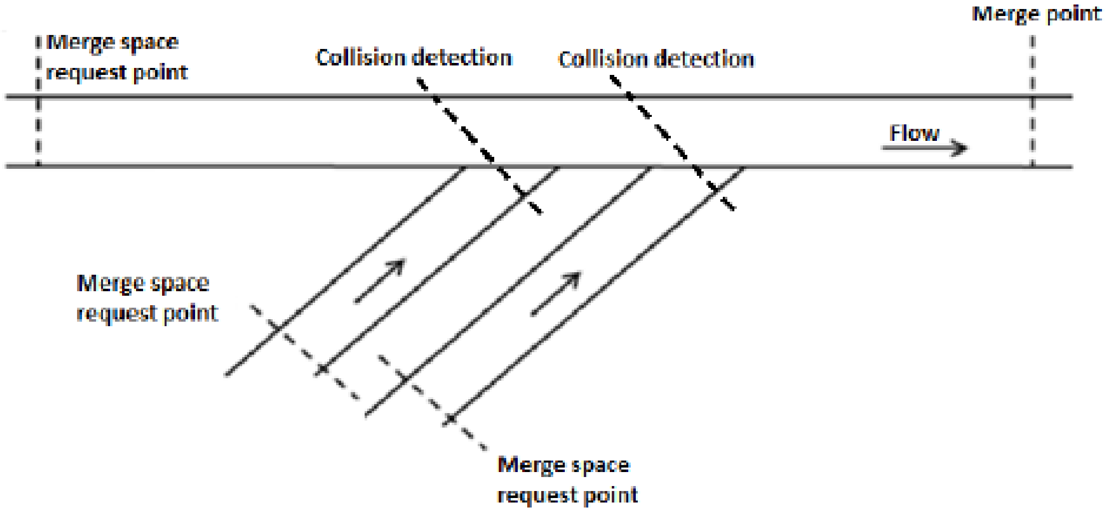

Fig. 1 Merge area

For merge area are analysed algorithm rules in conveyor warehouse systems: First in first out (FIFO) which gives priority to the first served parcel. Infeed line priority gives route to infeed line and from main line parcels are delivered only when space gap is allocated and it can be in opposite way. Merge flush – implement parcels from lines when it is accumulated at described number and then spread to merge area. For flush rule can be given time period in which parcels should be spread when reached required accumulated number of parcels [6].

Close look to conveyor warehouse handling systems merge area were analysed by comparing existing FIFO with a merge flush functionality algorithm and created new logic to achieve better flow performance of the system.

First analysed and often used type of merge alternating logic is first in first out method. It spreads from each line set amount of parcels in logic that first arrived parcel to merge space request point is spread first. For this function can be set what amount of parcels needs to be sent from each line. It can vary from design of the system.

To improve system the new algorithm was created for merge area. In this method the infeed conveyors will merge into the main conveyor line which has a priority flow. Parcels length vary from 228 to 600mm in that case flow in main line are created with different size of free gap space up to 542mm which can be filled with parcels from infeed lines. Maximum cartoon box size can be 520mm and tote size 600mm from that can be concluded that not all parcels can be filled in gaps on main line and additional logic will be needed to increase gap size. When parcel on main line goes through merge space request point the free space gap is measured until next arriving parcel reaches the sensor. If measured gap have time parameter in which can be filled delivery from infeed than line is working without any corrections, but if gap is smaller and delivery can't be filled from infeed to merge area then gap is created by stopping main line flow for required time to create gap for parcel from infeed. When a position on the main line is not available then the infeed conveyor will accumulate. Once a space becomes available on the main line, the system will automatically transfer a parcel across and the normal accumulation sequence will continue. Main line will have a constant flow and for infeed lines will be created available space gaps of maximum parcel size on main line to fill free space on merge area. Infeeds are working with FIFO function to spread parcels to main line.

3. Results

To find required parameters for analysis were used Siemens Step7 programming software with SIMATIC S7-300 programmable logic controller (PLC) and Xcelgo Experior 6.0 emulation software for conveyor which allows to work with real time system with exact parameters used in PLC. Emulation are conceived to help with presenting initial solutions, simulating product throughput, system operation, and carrying out detailed control of the system [5]. Once the model has been constructed and the logical flow of parts through it has been created, it is ready to be used for analysis of both methods.

First was tested existing alternate block – first in first out. With conveyor speed of 1 m/s was achieved result of 71 parcels per hour. Low space utilization is affected by different sizes of parcels and gaps between them. Before merge area are connected accumulation conveyors, which have windows of 770mm for each parcel. When deliveries are sent in required amount there occurs large empty gaps between them. When from each line are spread group of parcels then gaps are variable size and in them could fit another deliveries. With FIFO method the result was reached by 71% of space utilization and 100% in balance of the system in merge area. Another method used in analysis is with constant flow from main line and set window size for infeeds to spread parcels in to gaps. This method will allow better use of space utilization on conveyor merge area. With implemented new method were reached result of 78 parcels per minute which is 78% of space utilization and balance in the system was stable as well.

4. Conclusion

From simulation based experimental analysis of conveyor merge area were performed two types of methods for conveyor logic control. By comparing results of both methods can conclude that throughput in merge area has been improved by 7% and system balance remained the same. When hourly rate in logistic centres are thousands of deliveries per hour, achieved 7% improvement in merge area system performance can be well used to increase whole warehouse performance.

While conveyor warehouse systems becomes more complex, it is important to find better solutions for system and optimize process structure. To make process more efficient it was decided to investigate possibilities of Merge operation with different algorithm logics by improving system throughput.

References

1. **Johnstone, M., Creighton, D., & Nahavandi,** S. (2010). Status-based routing in baggage handling systems: Searching verses learning. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 40(2), 189-200.
2. **Gunal, A. K., Williams, E. J., & Sadakane,** S. (1996, November). Modeling of chain conveyors and their equipment interfaces. In Proceedings of the 28th conference on Winter simulation (pp. 1107-1114). IEEE Computer Society.
3. Keep materials moving [interactive], [accessed 2019 04 02]. Internet access: https://www.mmh.com/images/site/MMH1104_EquipRpt_Conveyors.pdf
4. **Arantes, J. C., & Deng,** S. (1996). Modeling and solution methods for the design and control of conveyor systems with merge configuration. Progress in Material Handling Research, 35-50.
5. **Laroque, C., Himmelspach, J., Pasupathy, R., Rose, O., Uhrmacher, A. M., & Gregor, I. M.** INTRODUCTION TO EMULATE3D–EMULATION, SIMULATION, AND DEMONSTRATION.

6. **Johnstone, M., Creighton, D., & Nahavandi, S.** (2015). Simulation-based baggage handling system merge analysis. Simulation Modelling Practice and Theory, 53, 45-59.

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Automated warehouse conveyor systems merge operating area throughput and workload balance system research

S u m m a r y

An experimental simulation analysis of conveyor throughput and system balance of merge area were carried out with different type of algorithms used to merge lines together. In the research was analysed existing first in first out logic and reached result of 71% in merge area throughput flow To increase productivity was created new logic where main line has constant flow and infeeds spread parcels in empty gaps which are length of 600mm. With created new logic was reached better result in merge area throughput flow by 7%.

Keywords: Merge, space utilization, throughput, system balance, conveyor, warehouse logistic.