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OPERATIONS AUTOMATIZATION AND DIGITALIZATION – A RESEARCH AND INNOVATION COLLABORATION IN PHYSICAL WAREHOUSING, AS/RS AND 3PL LOGISTICS CONTEXT

Case study Research report 2018

Operations automatization and digitalization – a research and innovation collaboration in physical warehousing, AS/RS and 3PL logistics context

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Forewords

This research work is collaborative RDI study written as part of DigiKaappaus research. The study focuses on current challenges in logistics automation and operations digitalization, in which the prediction of future bottlenecks is a key aspect for producing efficient digitalized logistics services for end customers.

The study itself raised interesting point from related literature, as part of the work we found out that there is not that much studied related to ASRs bottlenecks, even when it is quite obvious that nowadays, when international shipment and logistics is more important than ever before as a mean to provide a competitive edge and additional efficiencies to company's business practices. As researchers and University – Industry collaborators, we would like to give our warmest gratitude for our company partner, for providing us this challenging research case, offering highly valuable support (both in expertise as well as in data from), plus being so open in collaboration and open eyed for new ideas and concept development work.

Keywords: Automatization, Digitalization, Innovation, Collaboration, Warehousing, 3PL logistics

05.12.2018 / Daria Minashkina and Ari Happonen

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1. INTRODUCTION

This report presents the practical field research collaboration work done with a 3PL logistics operator, based on holistic collection of research data, analysis, development ideas and RDI points that has been surfaces in this industry – university collaboration efforts. For those readers, who are interested to study more on benefits of collaboration, we encourage to familiarize with the following studies (Salmela et al. 2007, 2011, 2013; Happonen et al. 2015; Rantala and Happonen 2012; Happonen and Minashkina 2018).

The report specially focuses into the process of analysis to identify possible bottlenecks in the Automated Storage and Retrieval System (Knapp, 2018) (AS/RS hereinafter) used by the case company's head office and warehouse unit. For those readers, who are interested to study more about AS/RS and AVS/RS (autonomous vehicle storage and retrieval systems) systems, we encourage to look to work done by (Heragu et al., 2011). Subsequently, this report also contains various development ideas for higher rate of utilization of the AS/RS, without a fear of experiencing some future related use case bottlenecks. In order to meet the goals of analysis the research is approached through different study methods, data collection ways and analysis, including following:

- AS/RS performance vs. order data
- Visualisation of the tote routes and paths in the operations sites
- Warehouse totes route analysis
- Warehouse tote route time delay calculations
- Comparison of different example months to each other
- Error station analysis

2. AS/RS RELATED OPERATIONS DATA ANALYSIS

To be able to do the analysis and to get “under the surface” of the totes’ life in the warehouses, different data sets from AS/RS machine operations was used. First used data set comes from March 2018 as it was deemed to be a good starting point for the analysis (operations around AS/RS were in stable state). For example, the data from February contains too much change operations done with AS/RS unit and e.g. data from April was known to have some collection gaps that might affect the analysis.

So, in order to demonstrate the warehouse performance as in the most typical / ordinary times, it was decided to use the March 2018 data and compare it to August 2018 data to see possible improvements in performance over the time of use of the system.

2.1. Months performance and material flow overview

Starting with the warehouse, in August its output in terms of order completed exceed two times March total completed order numbers (42282 vs 24967 orders). Comprehensively, the items quantity in orders follow the same tendency, in August the warehouse finished 1.5 times more work than in March (111450 and 72488 items respectively). Now, speaking about different types of orders, in March the biggest share of orders belongs to one made by private customers of the case company business customers (B2C orders) (the Figure 1). Same pattern repeats in the August data chart too (the Figure 2).

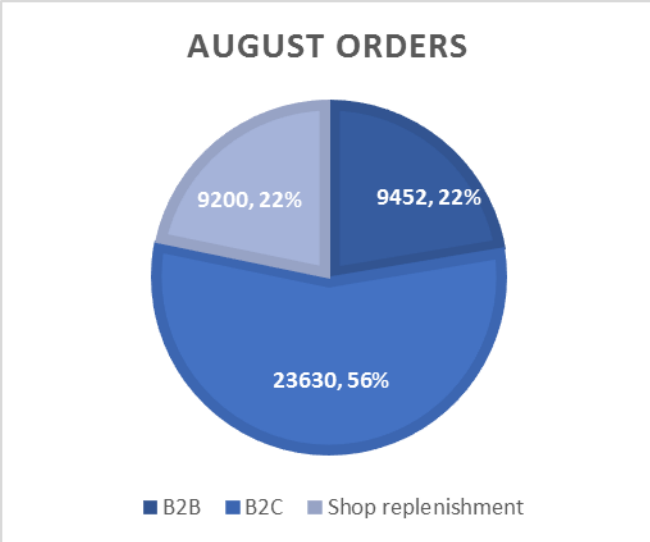


Figure 1. August orders description

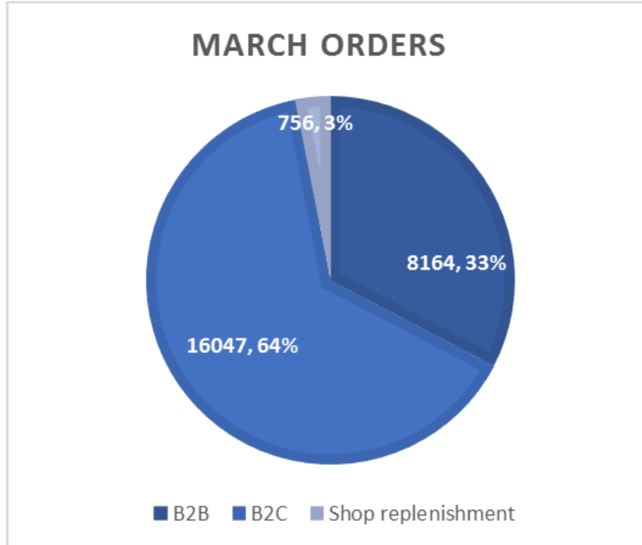


Figure 2. March orders description

However, the august order types look more consolidated rather than the March orders because in the august the percentage of shop replenishment and B2B are equal to each other (22%) and only two times smaller than B2B orders (56%). Whilst, in March the distribution of orders was more in the B2C side (64%), B2B did drop from 33% to 22%. the big exception / change happened with shop replenishment orders, as that was earlier significantly smaller (only 3%). And then, if we look up for the main lines of orders, the biggest number of items ordered are in the B2C style orders, while business orders are the smallest (in both Figure 1 and Figure 2). In average, the highest amount of orderliness per order is found in shop replenishment orders types. For delivery times, the average delivery time for shop replenishment is the highest one and the B2C end customer orders are orders that require fastest delivery times.

Usually, number of order lines equals to a number of items in order. The only exception to this rule was with shop replenishment orders (the table 1). In this table, the number of average order lines and average number of orderliness per order are shown together.

Table 1. Average order lines and quantity per order.

	B2B		B2C		Shop replenishment	
	March	August	March	August	March	August
items quantity average per order	2.10	2.35	1.35	1.44	45.00	5.99
order lines average	2.06	2.21	1.35	1.44	10.26	2.23

The next Figure 3 illustrates the maximum numbers in different orders. Within the analysis times, only shop replenishment shows increase from March to August. Specifically, maximum order lines/order (82→109) and maximum ordered item quantity (500→1300). In the B2B and B2C orders, the numbers were almost the same. By analyzing the data, this phenomenon can be explained by the share of shop replenishment orders, which has grown up greatly in numbers, when compared to previous months. On other hand the, while B2B and B2C orders have kept nearly the same order details proportions as they had in March.

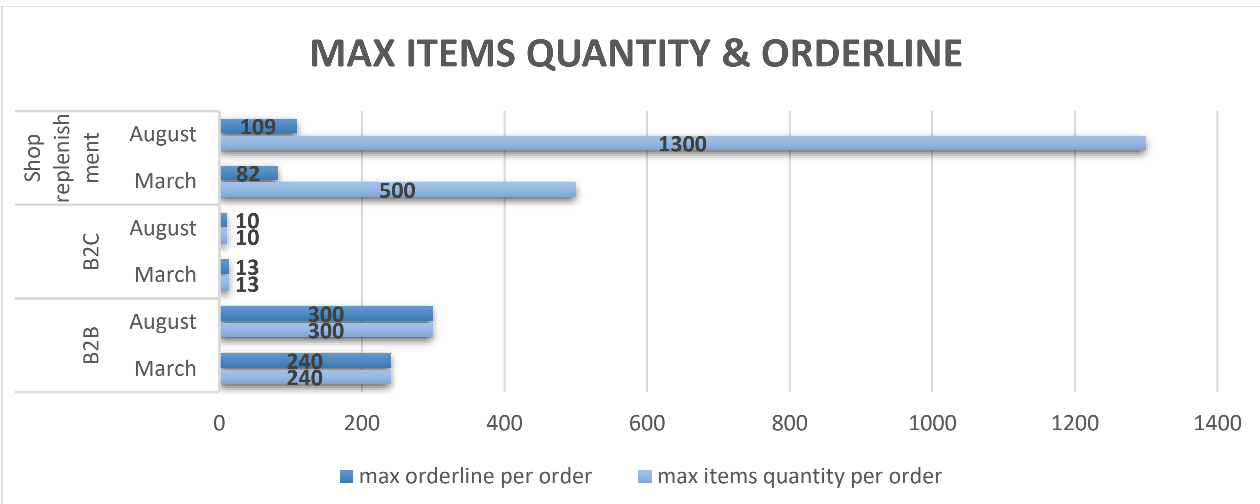


Figure 3. Maximum items quantity and orderlines.

2.2. Orders completed time analysis

The Figure 4 bellow depicts delivery time measurements minimums, average and maximums generated from the warehouse performance data. The data is presented for all three typical order group types (B2B, B2C and shop orders). In this figure two bars shows the average and min delivery times. Bar graphs values are to be read from the left vertical axes. The grey line in the figure illustrates the maximum delivery time. Values for maximum delivery time is to be read from the right vertical axes.

By looking up the visualized bar chart (the Figure 4) it can be said that this warehouse does better shop replenishment and B2B order completion, since their ready time was decreased. For both order types this performance indicator really tells something about active development efforts, as number of orders have grown in both order types inside the analysis window.

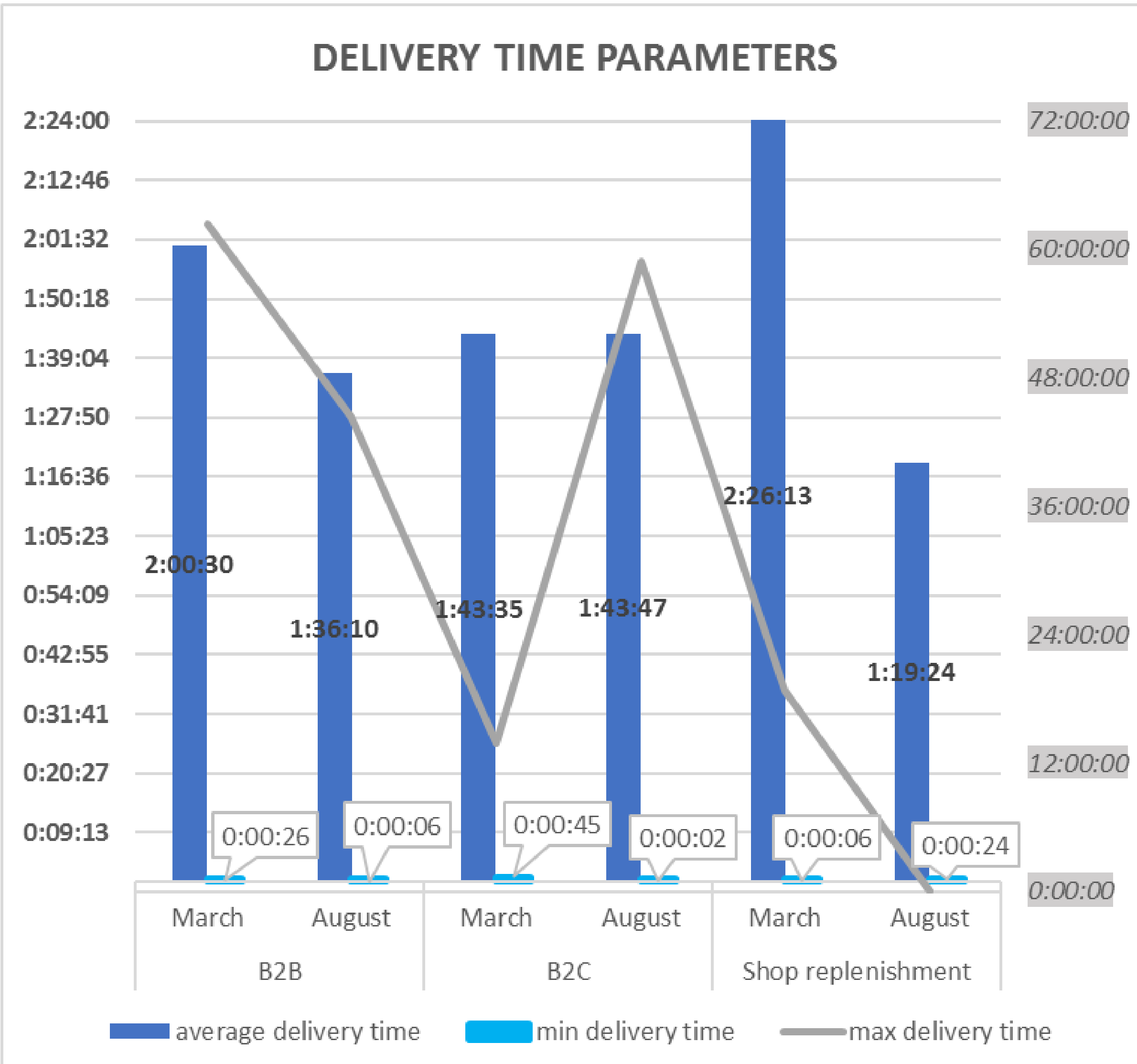


Figure 4. Delivery time details.

Related to different end customer sectors, this logistics operator does serve B2B clients who has their customer coming from B2C markets. According to Postnord (2017, 14) research, the average Finland's B2C sectors consumer's typical order to delivery wait time tolerance level is around 4.1 days. Considering the tolerance, warehouse operations could be optimized in collaboration with the B2B customers, if end customers would be e.g. offered different delivery time options (with price compensations) based on time these customers would be willing to wait for their orders. The optimization would be possible, as nowadays the average picking and packing delay is only roughly 2 hours (based on March data) and around 1 hours 40 minutes (based on August data). Typically, the contracts with the operator's clients do have little bit more flexible time frames, but on another hand if the end customers (people eventually receiving the items) would flex their expectations, the B2B customer for the operator could do the same too.

Now by continuing the data analysis, we also did build graphs for the working week of March (week 11) and August (week 32) according to B2B, B2C and Shop replenishment orders which shows order items quantity/order lines numbers change on different working days' time. In each graph, there are two lines: start (blue) and finish (orange). The start line means order items quantity/order lines numbers were registered in the system and the finish line when these order items quantity/order lines numbers were packed. All volume working week fluctuation graph in big formats to easily see values can be found in the appendixes 1-3. The main differences pin pointed in review process have been also marked in appendixes graphs 3-6, using clearly shown red circles. From these graphs, it can be concluded that:

- B2B customers' orders have the biggest amount (800) of the working queue of order items quantity & order lines numbers on Mondays, compared to any other order types. Contrary, B2B order types have the lowest number of order items quantity & order lines on Mondays.
- During March and August weeks in B2B and B2C orders the number of order items quantity mostly are equal to order lines numbers and lines follow the same pattern except some graphs difference spikes in B2B orders. Whiles, the situation is different for shop replenishment orders in both months where graphs of order items quantity/order lines do not repeat each other in numbers so much and slightly fluctuates in patterns.
- In March and August from order analysis patters it can be said that B2C and Shop replenishment orders can be ordered in anytime 24/7, while there are no registered B2B orders at all on Sundays according to data.

2.3. Order completion rate

Looking at the data of registered vs completed order types (appendices 7-12) shown as columns of these finished and unfinished quantity it can be judged that the number of not finished orders in August compared to March has decreased by nearly 32% (71 vs 104 orders).

In March 104 orders (B2B=16, B2C=88, Shop replenishment=0) were not finished and transferred to another month, while in August this number was 71 (B2B=2, B2C=34, Shop replenishment=35), even though the total flow of orders in the warehouse was bigger in August.

The appendices 13 to 24 also reflect the difference in number of not completed orders according to each order type, namely, how the warehouse deals with different quantities. Specifically, if a part of the line in the visualised pictures is in the negative side of the scale, then that means that there are uncompleted orders to do. If the line in the figure is above zero, it indicates that this day company personnel have done more ordered that are registered in this day. Usually it means the operator catches up the buffer work from earlier day.

There Sundays are not included into graphs as not working days at all. There are not so many fluctuations of completed and not completed B2B and shop replenishment orders in comparison with B2C orders. On another hand, in Saturdays warehouse workers did work for some orders. Mainly this happened for B2C orders and some of B2B orders, while Shop replenishment orders were usually not registered on Saturdays. On Saturdays usually warehouse workers finished more for B2C and B2B type orders than were registered these days, plus, they tried to finish these weekdays orders too. With shop replenishment orders registered and completed orders numbers were equal.

2.4. Order patterns and trends

In order to identify trends in registered & completed order items quantity & order lines numbers, one-week data of March and August is analysed. The blue coloured line in below figures 5-10 is the trend line of each month week orders. This trendline is a visualization of the data made by authors. Usually, spikes of registered orders on Mondays to be worked out can be explained with the fact the warehouse does not work on Sundays at all, so all orders made in weekends will be moved to Mondays to be completed.

Similarly, both in March and August B2C order items quantity & order lines numbers registered and finished (Figure 5 and Figure 6) are high in the beginning of the week and decrease to weekends – so the trendline looks like a smooth slope

March week

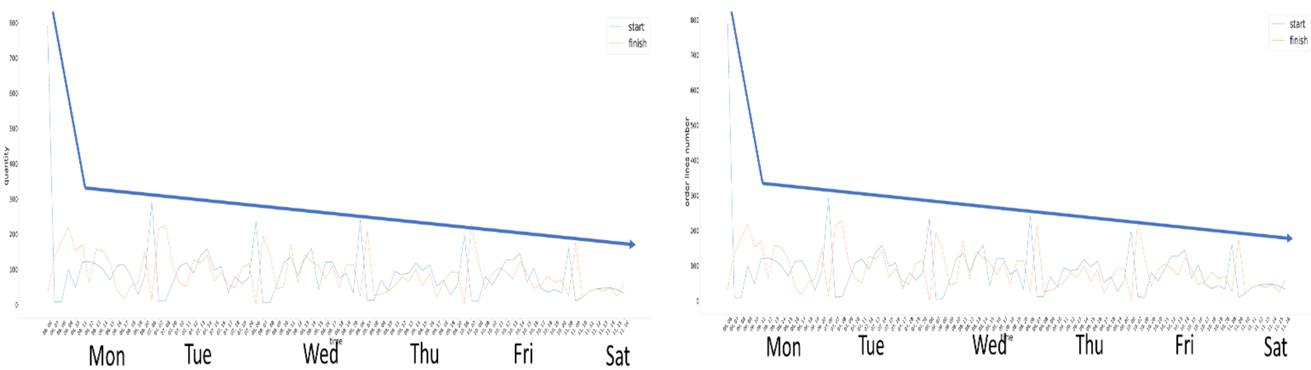


Figure 5. March week B2C trendlines in order quantity and orderliness number.

August week

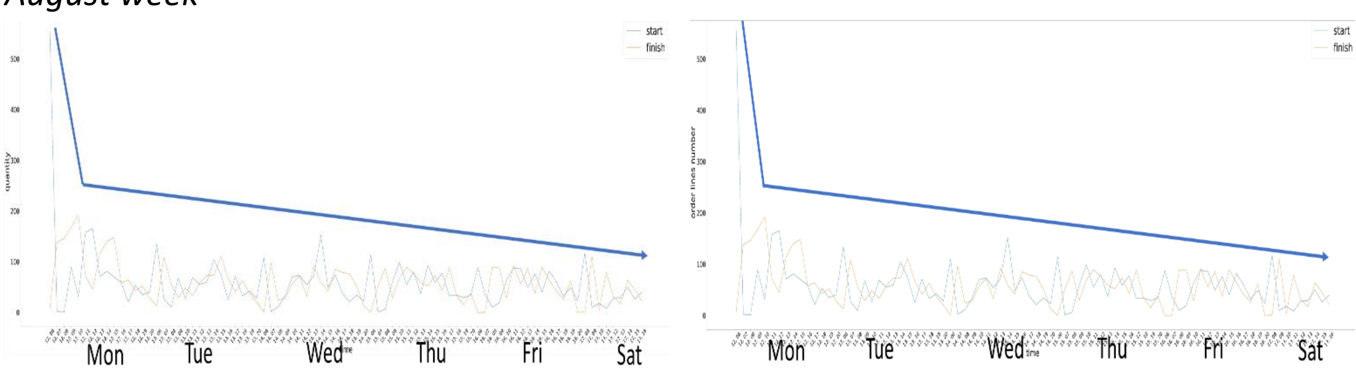


Figure 6. August week B2C trendlines in order quantity and orderliness number.

For March and August there are differences In B2B order items quantity & order lines numbers registered and finished patters.

March week

Namely, in March B&B orders increased on Tuesday end then after decline raised again to Saturday (the Figure 7).

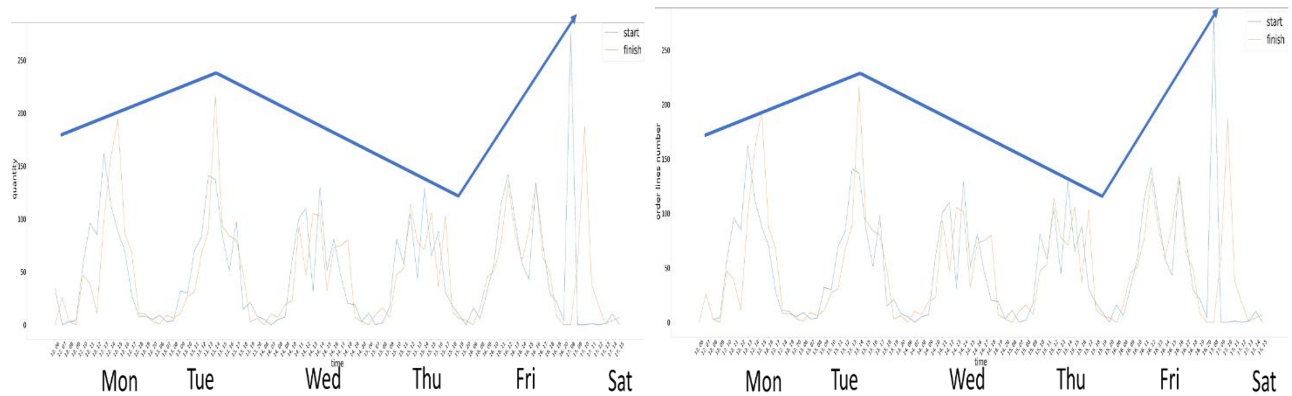


Figure 7. March week B2B trendlines in order quantity and orderliness number.

August week

While in August in B2B order items quantity & order lines numbers registered and finished have spikes in the middle of the week – on Wednesday & Thursday (on Thursday it is a bit higher) – the graph trendline looks like a hill (the Figure 8)

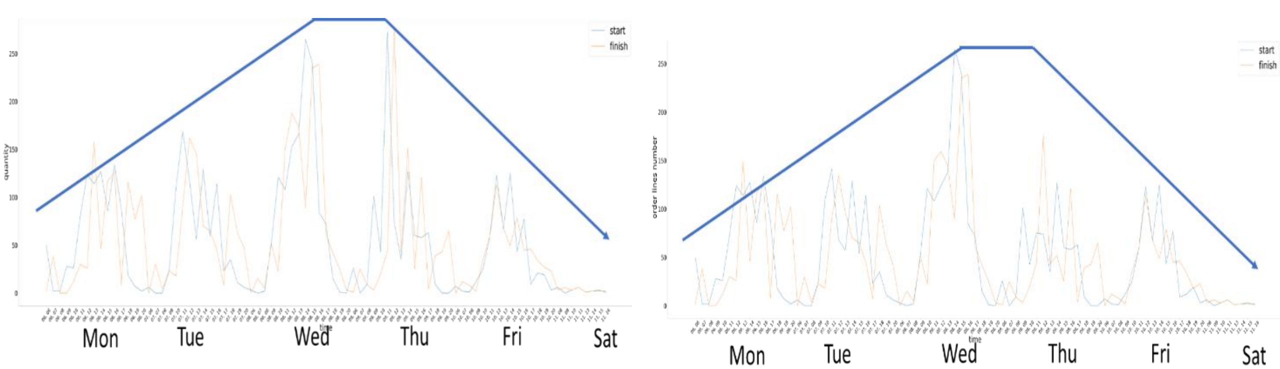


Figure 8. August week B2C trendlines in order quantity and orderliness number.

In the March week in the Figure 9 during March week there are increase of shop replenishment order items quantity & order lines numbers registered and finished in the middle of the week (Wednesday and Thursday)

March week

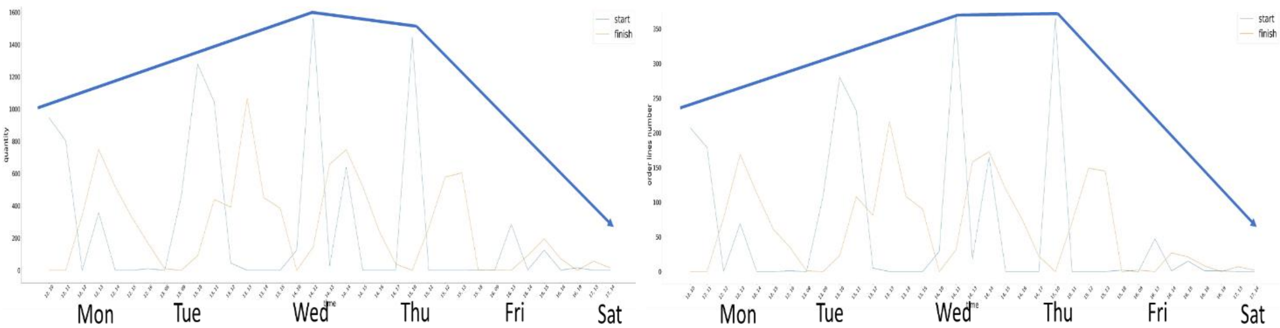


Figure 9. March week Shop replenishment trendlines in order quantity and orderliness number.

August week

In the Figure 10 Shop replenishment order items quantity & order lines numbers registered have its highs on Tuesday & Thursday decreasing to weekends. Interestingly that this type of orders graphs for finished quantity & order do not follow so much the same pattern of this order registered, so not all warehouse workers were put to complete these orders immediately.

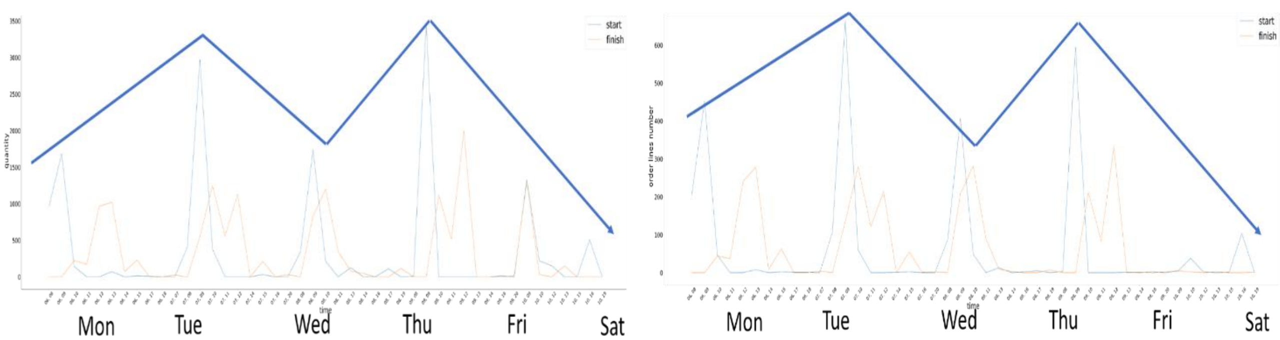


Figure 10. August week B2C trendlines in order quantity and orderliness number.

2.5. Registered and completed orders analysis in holiday time

The following analysis is built around week 10 holiday time to show how a holiday time might affect warehouse loads and how that affects warehouse activities.

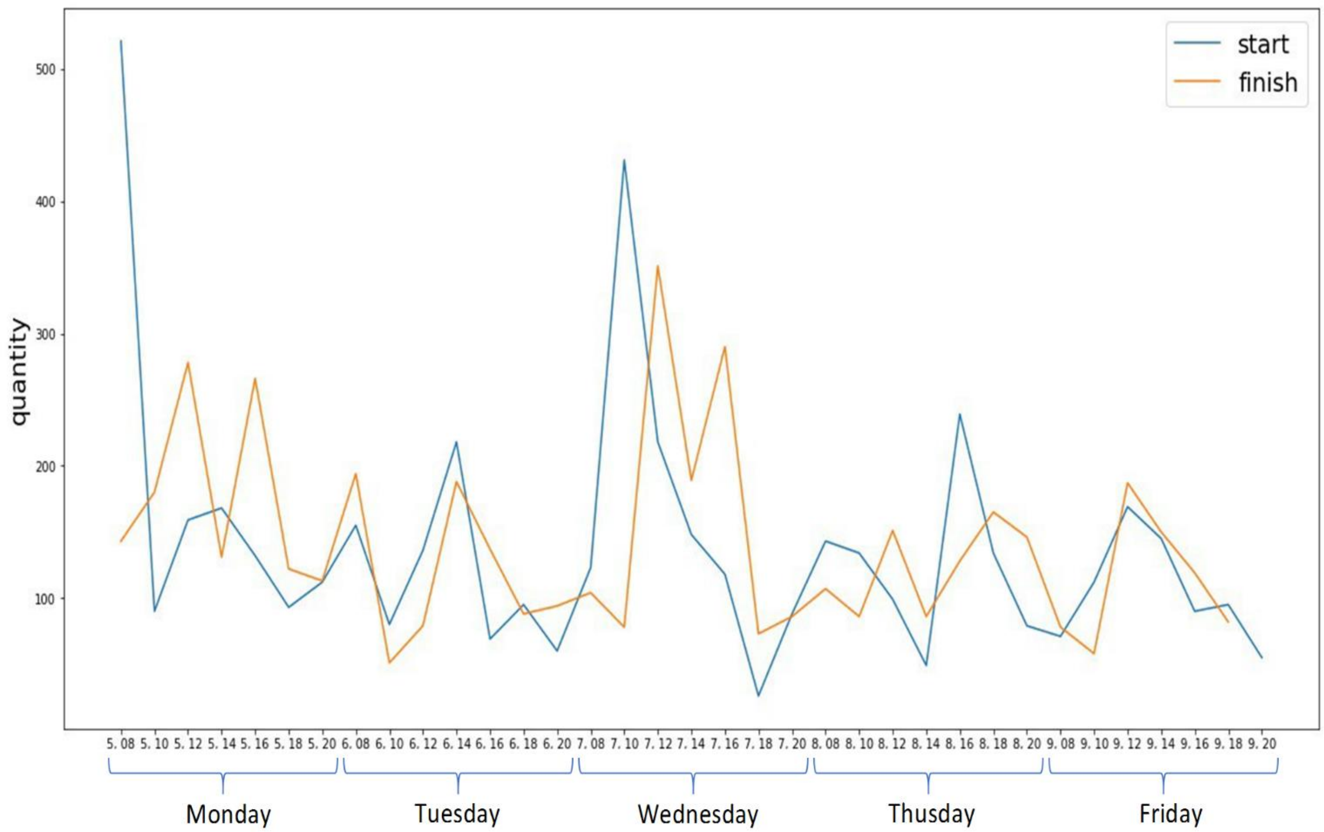


Figure 11. Registered and finished quantity in orders in March week 10.

The graph in the Figure 11 shows the items quantity of registered new work that should be completed in the warehouse. This is illustrated with a yellow line, in the figure. In this analysis, on Monday, one finds the highest amount of ordered items in the morning in comparison with any items quantity ordered within all the weekdays looked in this analysis. As the spike buffers extra work into the system, the warehouse workers need to deal with this Monday for all the week (some daily buffer work is transferred to following days). This is visualised in the trend line as delays and arbitrary spikes in finishing the work, compared to receiving (start) pattern of the work.

The graph can also explain the speed of quantity of items collection in different times of the day. E.g. following pattern of high speed in orders quantity can be noticed:

- from the morning to 1-2 pm on Mondays, Tuesday, Friday because of truck picking time at 1 pm
- at 12 there is a spike finished quantity for Monday, Wednesday and Friday
- from 2 pm to 4 pm on Monday, Thursday, Wednesday and Friday (also an increase on Thursday, but a pick was at 6pm) because of truck picking time at 5 pm
- speed of quantity collection declines till the end of the week
- Wednesday and Thursday bring some data distortion, especially in here, as this Wednesday was the Woman's day, so people order a lot (e.g.) presents, thus, the number of items ordered this day was high for warehouse workers compared to normal weeks. This special day did generate some work buffer for Thursday. This buffer is visualised as part of unfinished orders that went to be work for Thursday. This buffer also explains the reason for the additional number for completed work in these days. These holidays themselves are something we cannot change, but for warehouses and logistics companies it would be highly meaningful to investigate options to integrate more tightly to their customers B2C sales processes to improve vertical integration efficiency in supply chains (Yao, 2015).

3. TOTES "LIFE ANALYSIS" WITH TRAVEL TIMES AND ROUTES

This part of the report is discussing about the routes of the totes around the conveyer lines from order initiation from buffer, decanting, picking, packing and return to the AS/RS, it also opens up the time delays in the routes from point A to B and will be basis for later text chapters that discuses ideas around the findings made based on the route analysis.

3.1. A white tote from the 1st floor buffer goes to picking

– big picking station 1 min 37.09 sec = 97.09 sec
– small picking station 1min 44.73 sec = 104.73 sec

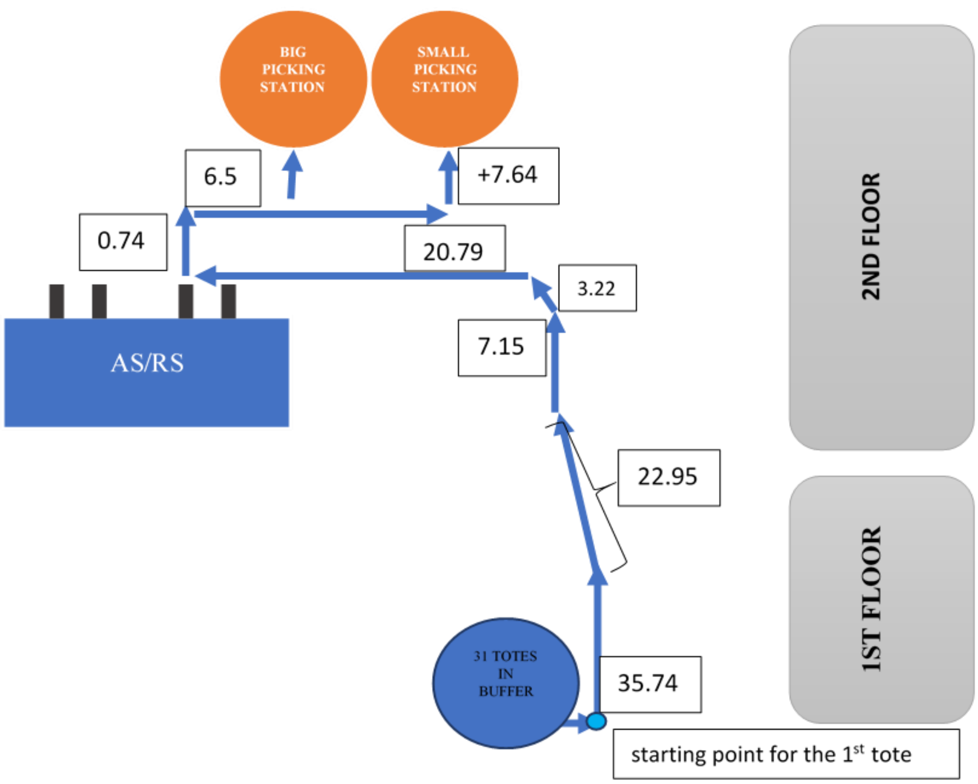


Figure 12. White buffer tote's path to picking.

3.2. A white tote after picking goes to packing from

- big picking station 59.94 sec
- small picking station 54.66 sec

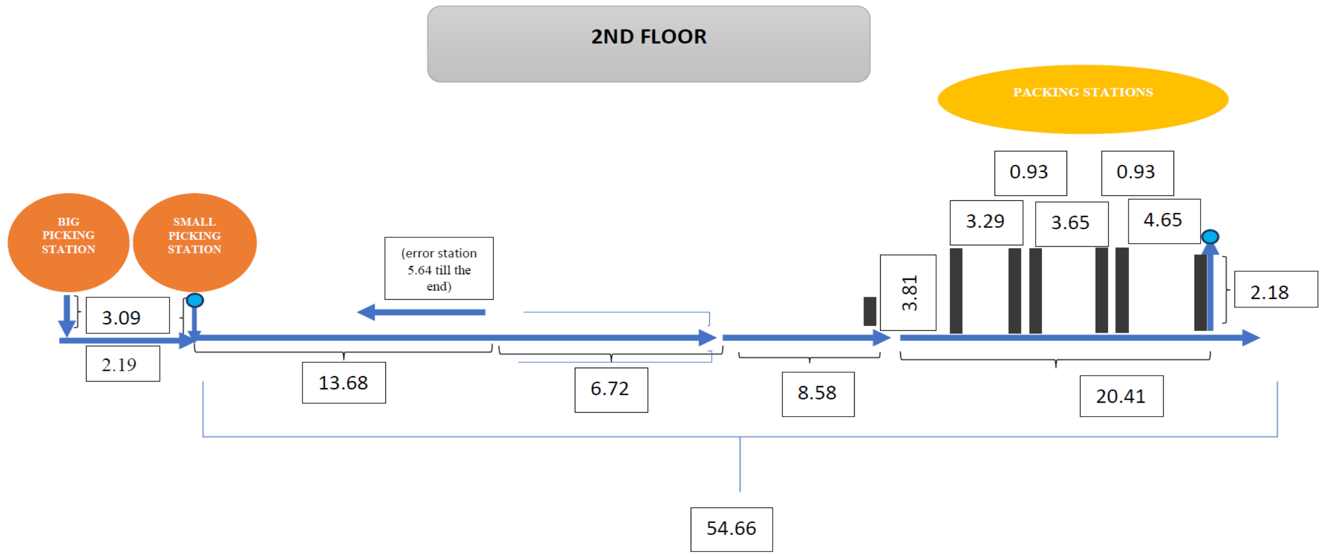


Figure 13. White tote's path after picking to packing.

3.3. An empty white tote after packing goes to

- AS/RS 1_point 1 min 9.19 sec = 69.19 sec
- AS/RS 2_point 1 min 16.42 sec = 76.42 sec
- conventional warehouse 2 min 13.8 sec = 133,8 sec

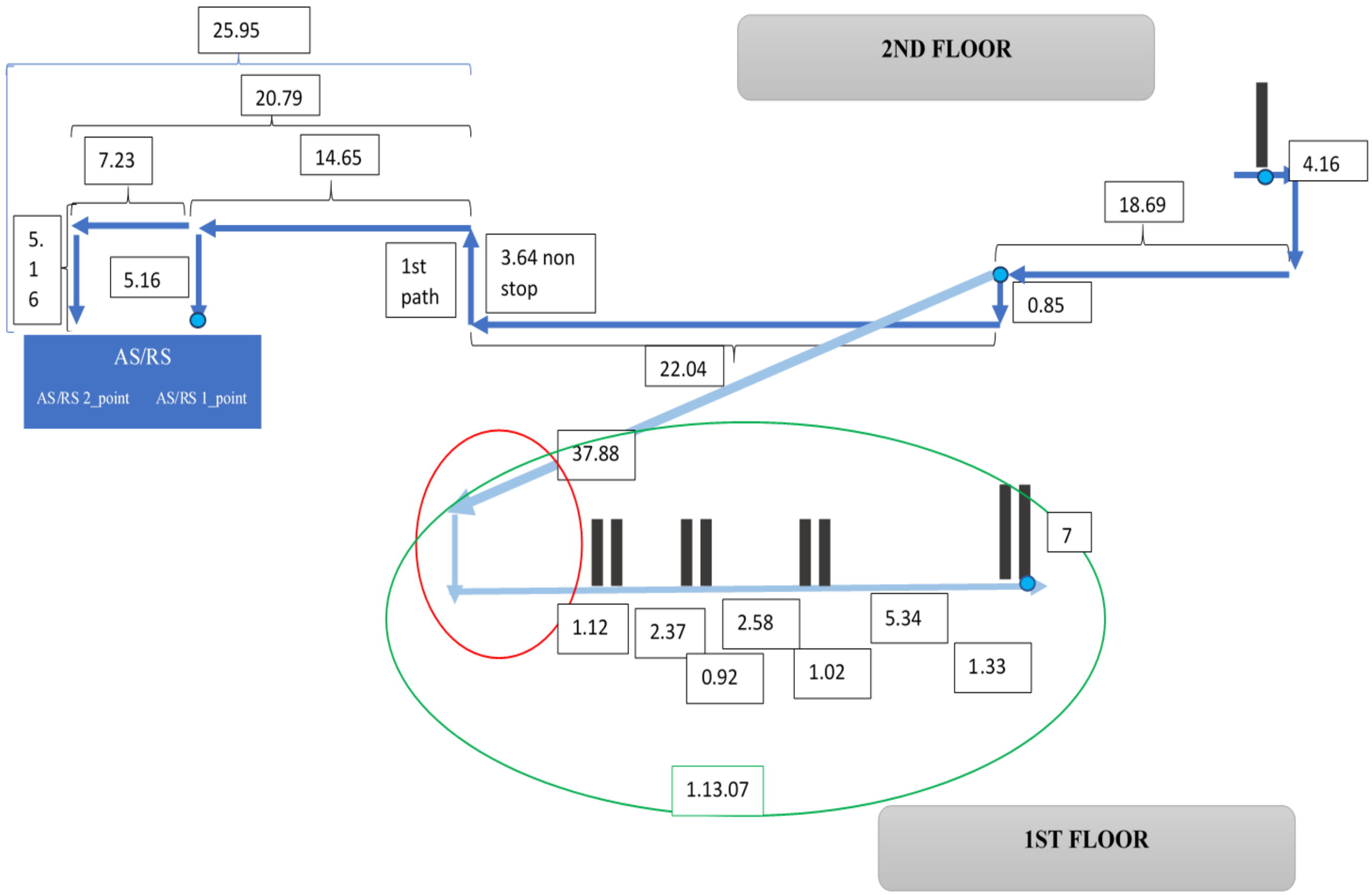


Figure 14. White tote's path from packing to AS/RS and conventional warehouse

3.4. The way how white totes buffer is formed in

- (till the end) 1 min 53.85 sec = 113.85 sec (the 12th buffer tote) 2 min 7.58 sec = 127.58 sec
- (till the end) 2 min 5.13 sec = 125.13 sec (the 12th buffer tote) 2 min 18.86 sec = 138.86 sec

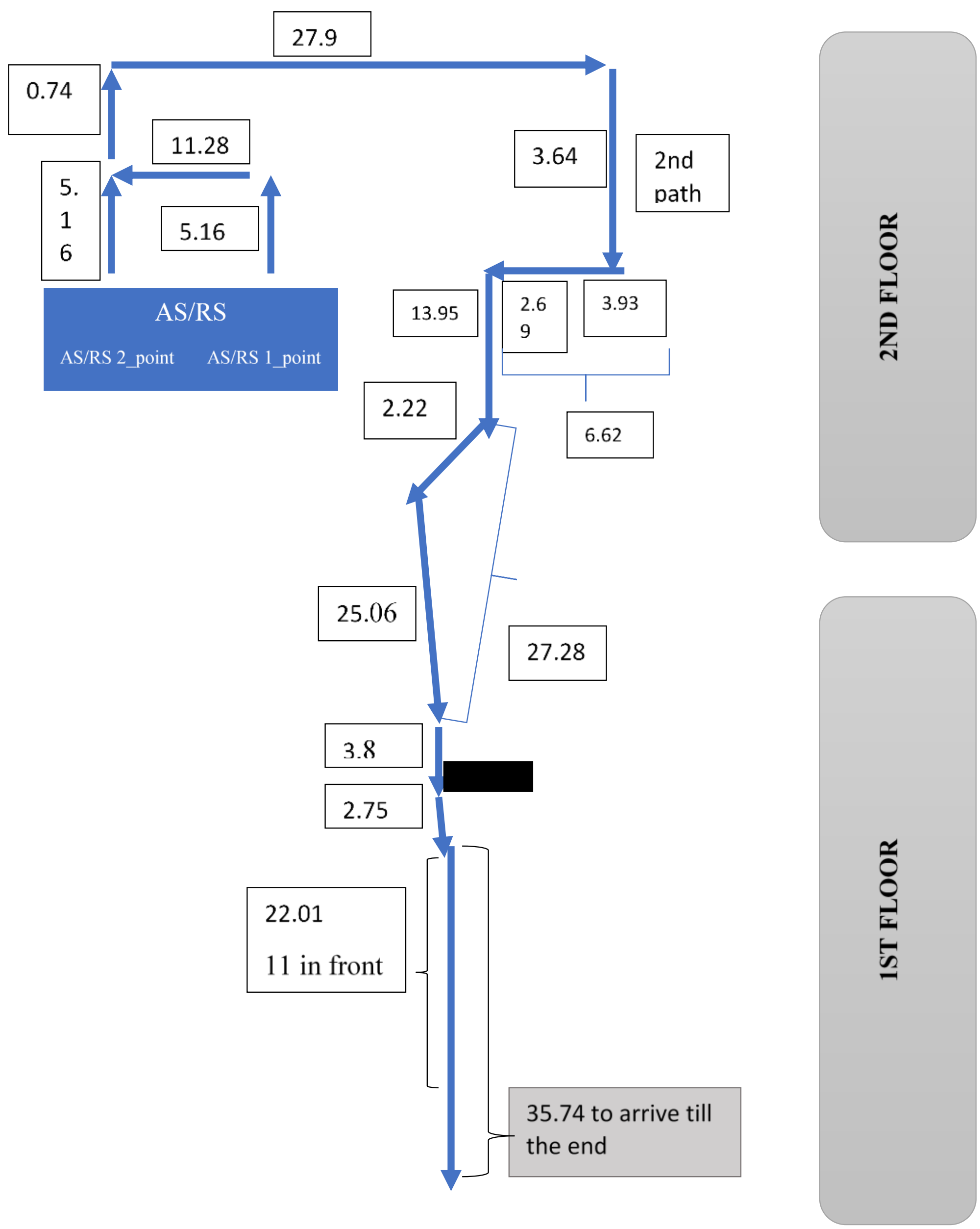


Figure 15. White totes' buffer formed.

3.5. A grey tote after decanting goes from

- decanting station_1 to:
  - AS/RS 1_point 1 min 15.67 sec = 75.67 sec
  - AS/RS 2_point 1 min 21.78 sec = 81.78 sec
- decanting station_2 to:
  - AS/RS 1_point 1 min 7.69 sec = 67.69 sec
  - AS/RS 2_point 1 min 13.8 sec = 73.8 sec

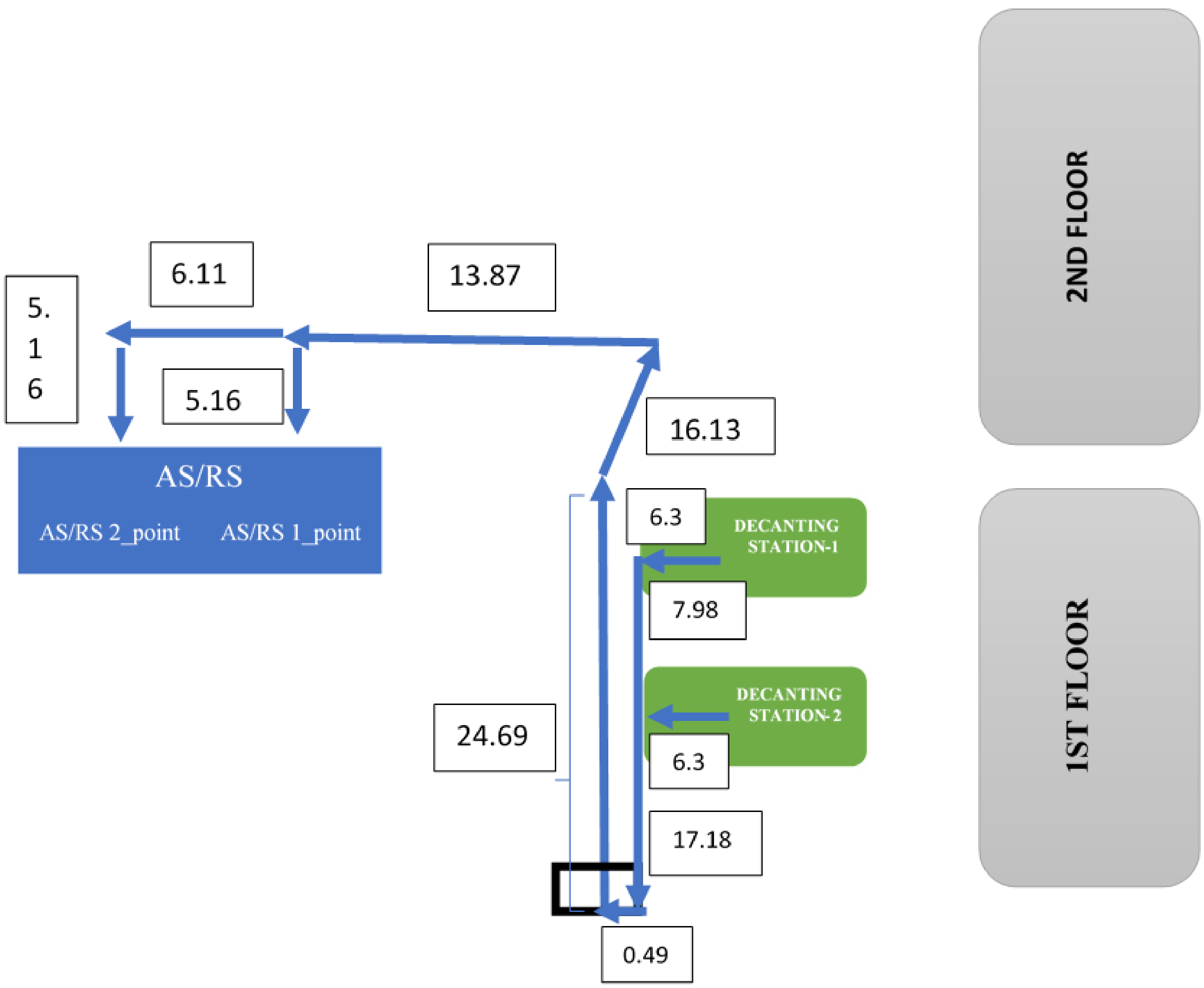


Figure 16. Grey tote's path after decanting.

3.6. A grey tote retrieved from AS/RS to picking and returns back to AS/RS

- AS/RS 1_point → small picking station→ AS/RS 1_point 1 min 3.3 sec = 63.3 sec
- AS/RS 2_point →small picking station→ AS/RS 2_point 1 min 3.3 sec = 63.3 sec

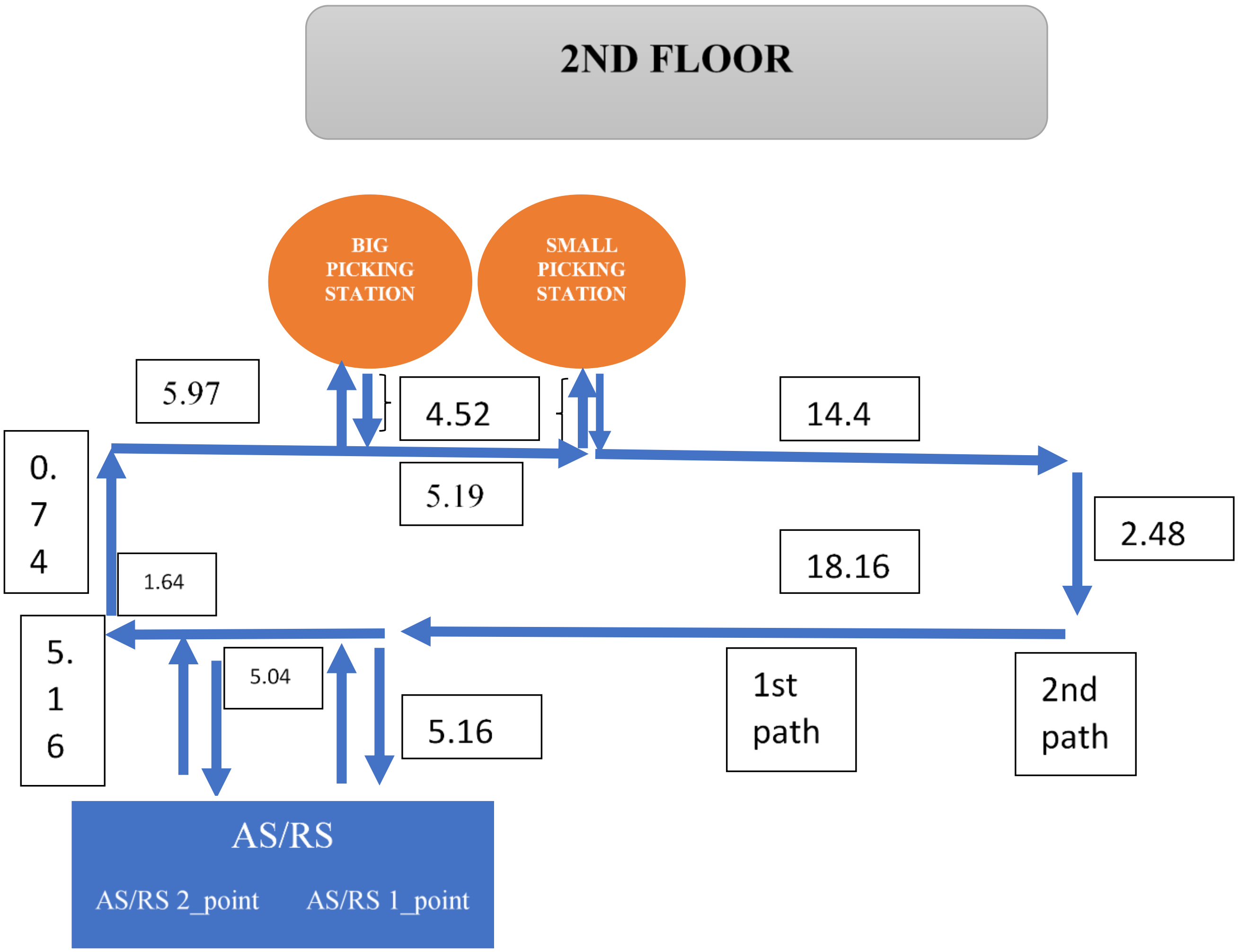


Figure 17. Grey tote's path from AS/RS to picking and back.

3.7. A grey tote retrieved from AS/RS to decanting station

- AS/RS 1_point to:
  - decanting station_1 2 min 9.1 sec = 129.1 sec
  - decanting station_2 2 min 1.12 sec = 121.12 sec
- AS/RS 2_point to:
  - decanting station_1 2 min 2.99 sec = 122.99 sec
  - decanting station_2 1 min 55.01 sec = 115.01 sec

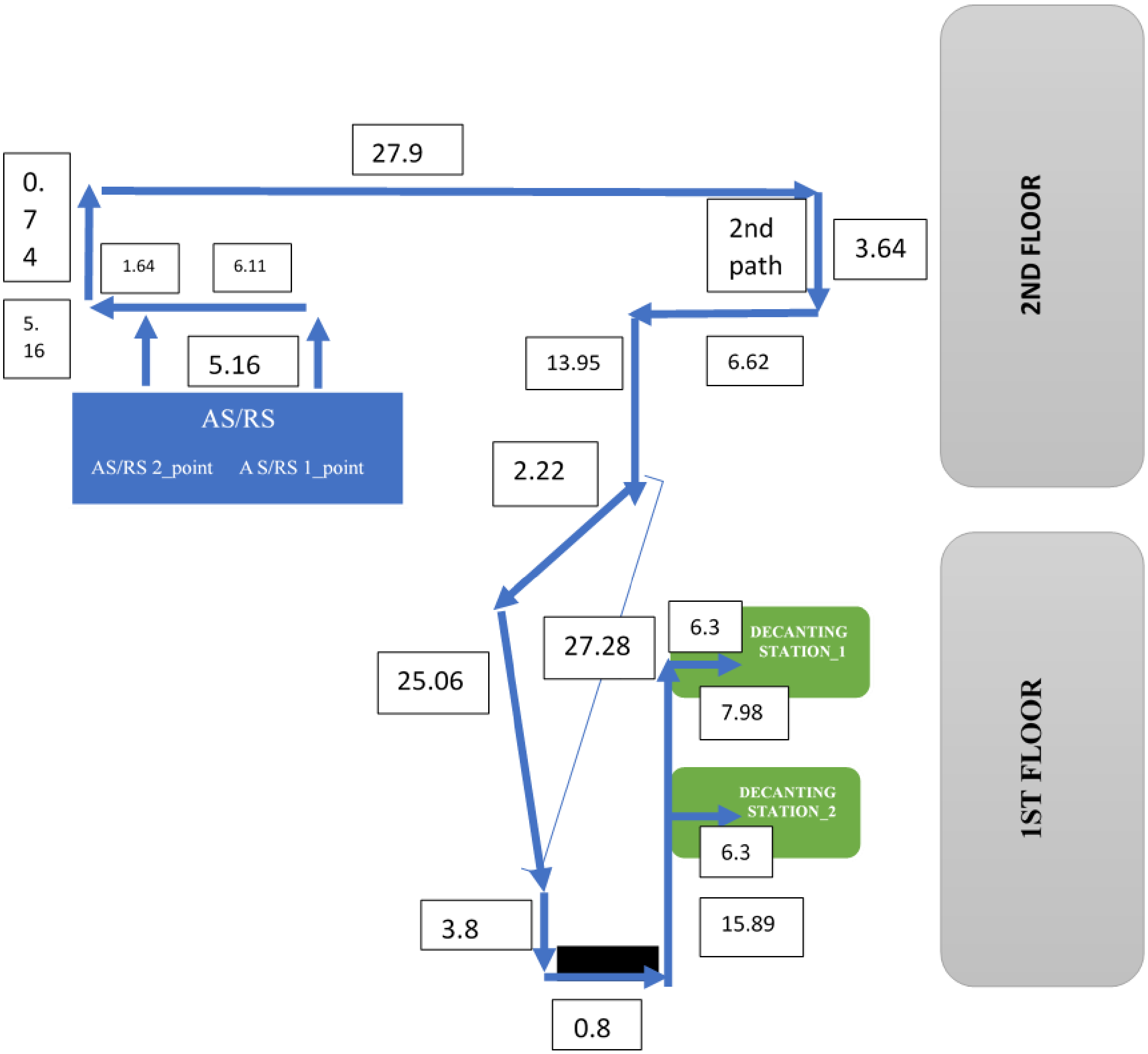


Figure 18. Grey tote's path from AS/RS to picking and then to decanting station.

3.8. Visualized summary for totes' traveling times

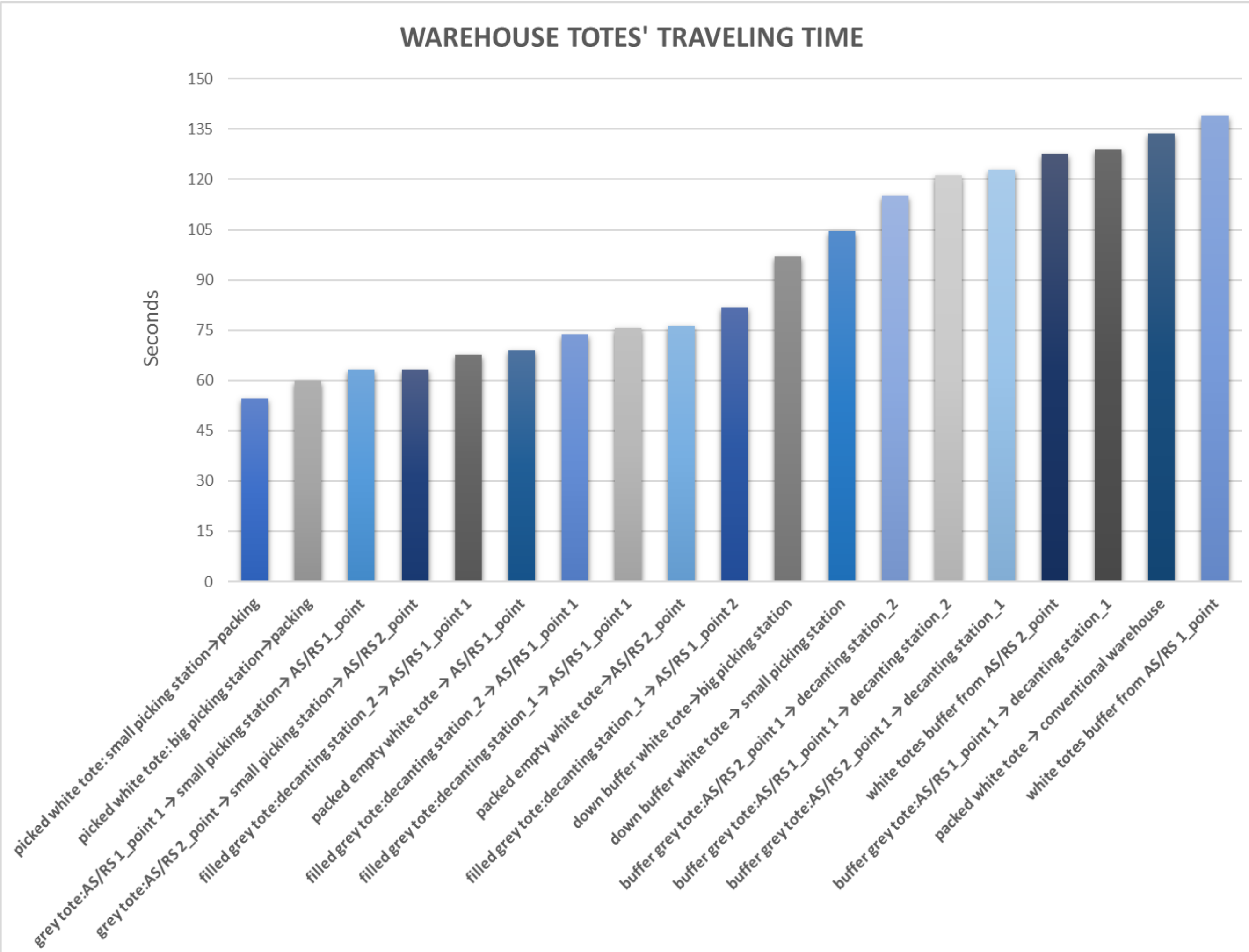


Figure 19. Totes' traveling time.

Starting from the point of view of totes traveling time analysis, generally white totes movements take more time than grey totes do (the Figure 19). However, the smallest time is required for already picked white tote from any picking station to get into any packing station (time varies a bit whether a tote go from small or big picking station and to which packing station within reasonable limits) compared to other totes time. Then, with further analysis, the second smallest travelling time is taken by grey totes from the AS/RS to picking and back, this time is the same if a grey tote returns to AS/RS point from where it is retrieved.

Contrary, the longest time belongs to recalling white down buffer totes to picking station when an order is initiated (traveling time to the small picking station is a bit longer than for the big picking station). Moreover, this white buffer totes long traveling time means long waiting time for a picker for a target tote. Quite same situation with one of the longest traveling time is with buffer grey totes retrieved from the AS/RS to any decanting station. Still a warehouse worker doing decanting do not need to wait a lot for empty grey totes to come because the buffer is located near decanting station, while white buffer totes have to travel more than 1 minute for picking. Forming grey totes buffer from the AS/RS takes long time too, but as our visits to the warehouse have shown warehouse workers doing this job do not experience any difficulty of the shortage of grey totes buffer quantity.

Another really long traveling time belongs to partly packed orders in white totes going down to the conventional warehouse. The issue of increasing conveyor parts there depends on whether workers on the first floor have to wait for this type of orders or they have enough tasks to do. Even though this kind of totes does not cause any totes jam because there are only these totes using conveyor going downstairs. Even though the time needed for a partly picked white tote to go to the conventional warehouse is one of the biggest, this kind of totes does not cause any difficulties because there are only these totes using conveyor going downstairs

Traveling time that is roughly taking an average time from a point A to B are e.g. traveling times for the packed white totes returning to the AS/RS and filled grey totes after decanting to the AS/RS (nearly 65 seconds).

In order to decrease totes traveling time, it is advised to accelerate speed in parts of the conveyor with these following totes routes for example with red circles in the Figure 23. Since saving of e.g. 10 seconds for each tote traveling time should improve the system and work efficiently. Moreover, workers do not need to wait for totes to come with travel delay. In short, there might be actually more money to be made with the option to speed up the conveyers (at least on some parts off the track, than what we have been discussing before).

3.9. Down level conveyor load

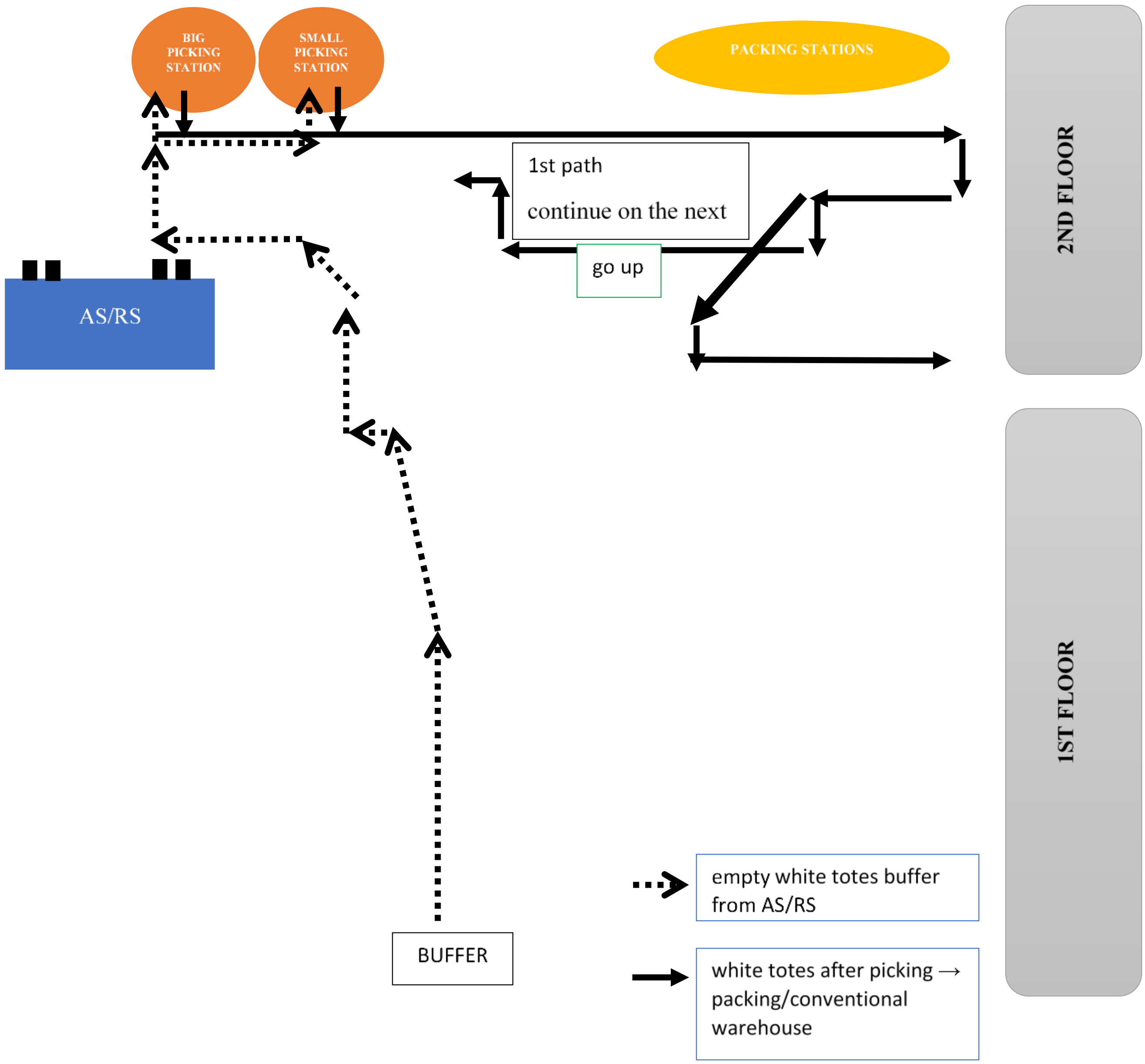


Figure 20. Down layer conveyor load.

3.10. Upper level conveyor load

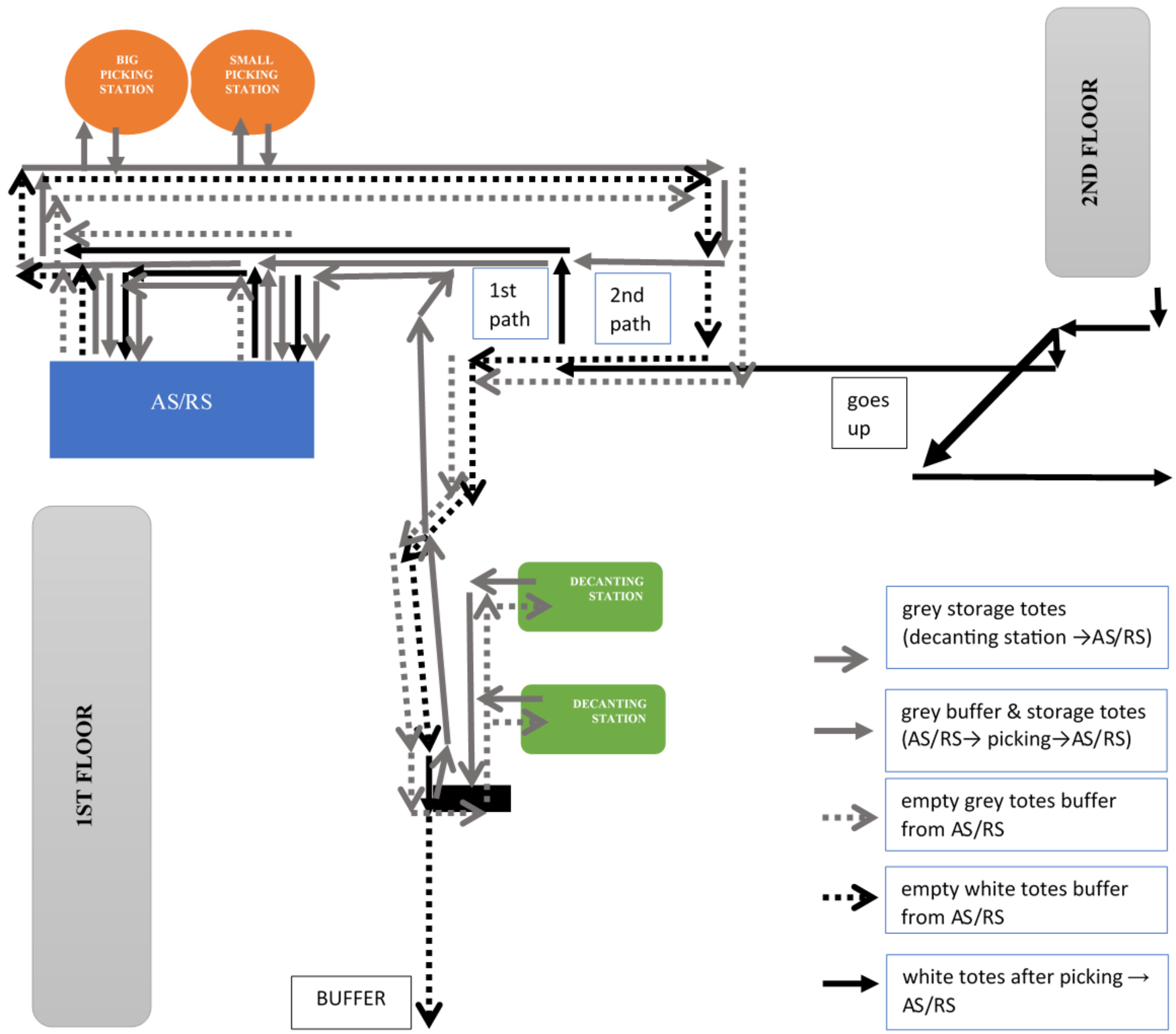


Figure 21. Upper layer conveyor load.

3.11. Development ideas related on totes' routes

In here, the ideas based on field measurements will be discussed that did surface from the field study of tote routes, from the time delay and speed measurements and observations made in the field e.g. about some blocking situations for totes in conveyer lines. For example, let's look the conveyer speeds on the Figure 22.

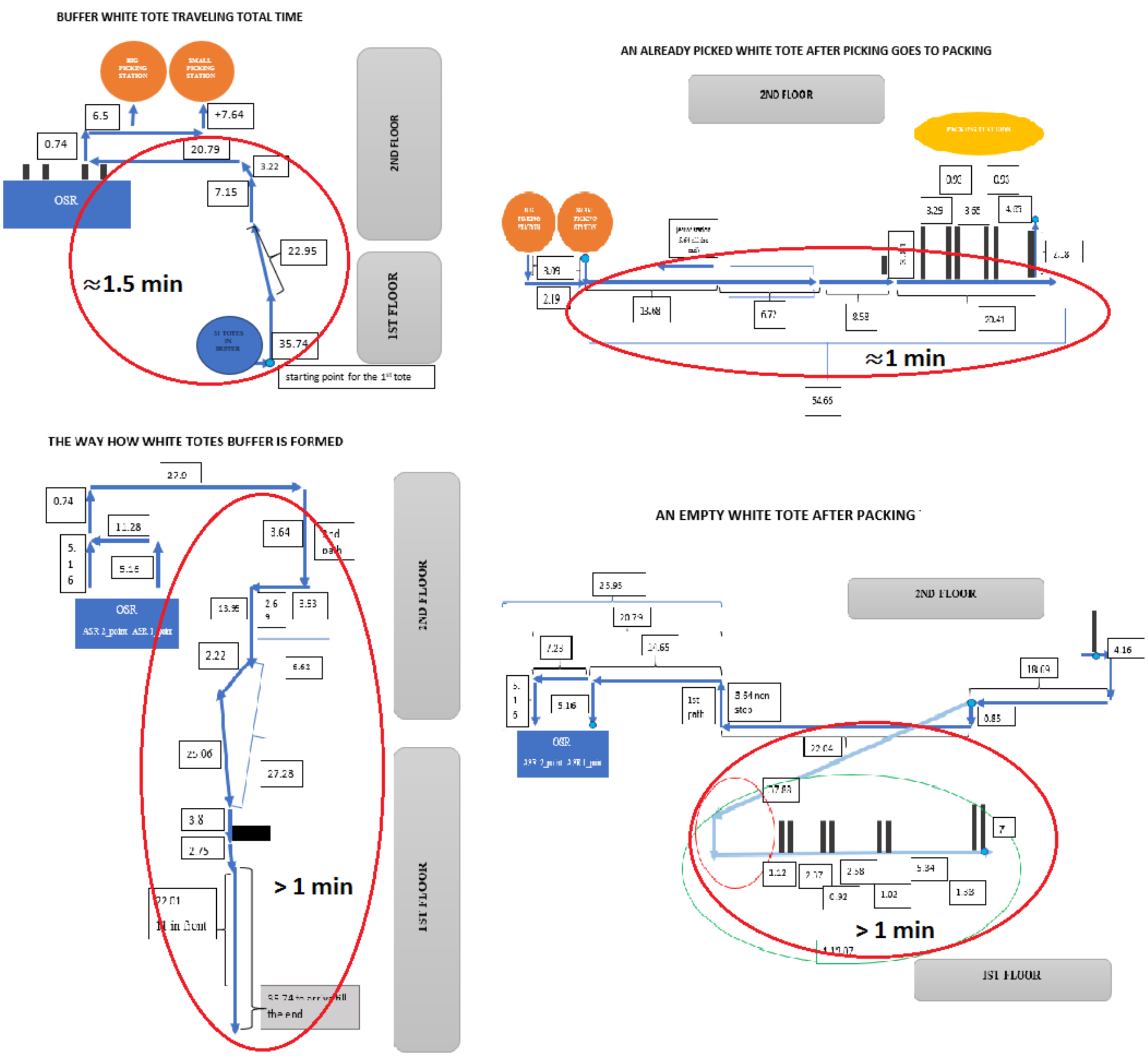


Figure 22. Conveyor parts for acceleration.

Coming to traveling totes routes it is recommended to pay attention for high totes traffic, namely, where there is more than one kind of totes traveling (look at the Figure 23). These conveyor parts are with traveling routes of: white and grey totes near the AS/RS points, near columns of totes paths 1 and 2, white totes buffer taken for initiated orders and grey totes filled with goods after decanting and formation of white and grey totes buffer. All in all, the huge totes rotation happens on the second floor between the AS/RS and path 1 and 2 angles.

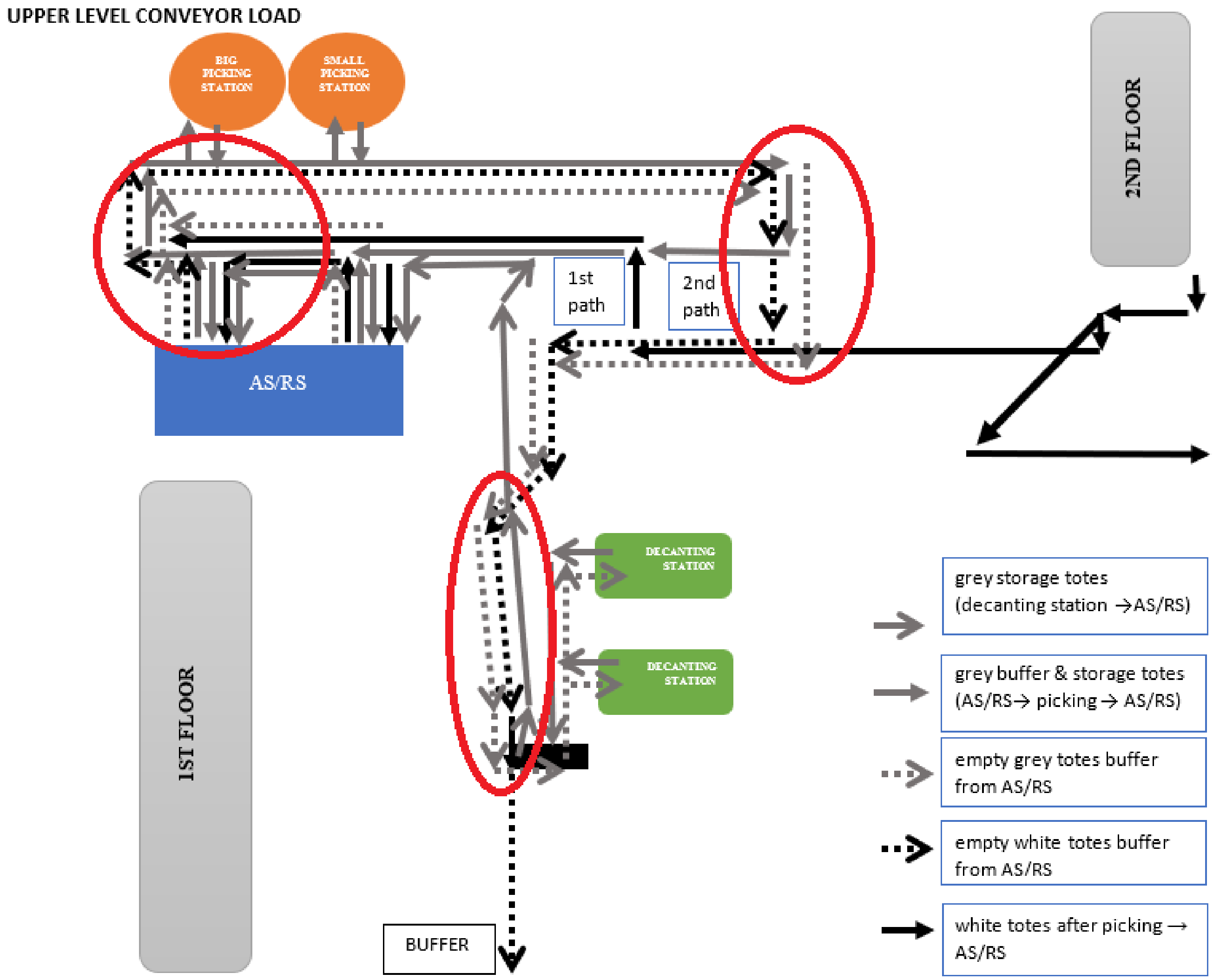


Figure 23. Conveyor totes high traffic.

4. CONCEPTS FOR NEW LOCATIONS FOR WHITE TOTES

The current process demands the AS/RS to feed the empty white totes to flow within the conveyer line all the way to the downstairs location to be able to start to be part of work flow in this AS/RS automated picking and packing operations process. Within current load of tote movement in conveyer liens, that is not an issue, and the system can mostly cope the flow quite nicely. But still, even in the current customer situations there were times when white totes with content put into the tote in picking station was blocked to enter in the conveyer from picking station towards packaging station, just because of the flow of empty totes going downstairs. Given the logistics operators hope to fulfil the AS/RS unit with larger SKUs set (new B2B customers for the case company), the situation would change and e.g. in case of few error totes doing “merry go around” in the conveyer at the same time both picking stations are constantly being worked all the time, there could most surely be some hick ups in the conveyers.

As for solution options for this challenge, different paths to downstairs were considered (more about that in following) and also new ideas for changing the white totes starting positions were considered and now documented in here.

4.1. New “free flow” conveyer line for white totes from AS/RS into the 2nd floor to the 1st floor conveyer downslope

So, let’s start from the ideology, that the location of white tote buffer would not be changed anywhere from the downstairs (option 1). that would mean that to be able to go around the blocking issue, the white totes would be needed to be removed from current conveyer lines => we need new line from upstairs to downstairs, just for the white totes.

Different options were look for in the current conveyer line configuration and basically only line that would not need to cross the current lines would be a separate output line for empty White totes. But as the current starting point is at the 2^{nd} floor, and that area is mostly built already, the feeding points would need to be somewhere between the 1^{st} and 2^{nd} floor. Different options were looked up with the case company, but all of them were finally deemed too costly to be arranged to be physically implemented into this warehouse environment.

4.2. New starting location and buffer line for white totes extremely close to the current picking stations

This ideology is based on an idea of building small additional conveyer line just in the end of the second-floor picking area (near the emergency exit door). This is the area, which has been originally reserved as a possibility for additional place to build an additional picking station. In this concept idea the current conveyer line will have a U track extension, in 2^{nd} floor, just at the end turn point where the input / output paths to AS/RS area. This is visualized in the below on the Figure 24.

Figure 24. New extension path for conveyer in the 2nd floor.

This new path / U turn track would serve as new white tote buffer and starting point for whole picking process. So, in short, when the system in the warehouse prepares itself for new orders, instead of buffering white totes to downstairs line, the buffer is formed in here, in the U track in second floor. The advantages this gives for the whole process are:

1. The White totes get really fast from AS/RS into the buffer. The current time delay is around 120 seconds, in the U track model it would be in 15 seconds range.
2. The feed to the buffer does not block ready picked white totes from exciting the picking stations into the conveyer to go towards packing stations
3. Feed from buffer into the picking stations drops from 1 min 30 seconds to around 10 seconds range
4. Empty white totes would not go into conveyer lines to fill up the downstairs buffer so that part of the conveyer would be free for grey totes to move more freely
5. A short burst of error totes generating a blocking condition between picking stations and packing stations do not block the picking stations to be filled with empty white totes (but in the long run that sort of blocking condition would block the already picked white totes to exit from picking stations and then the process would stop as in the Figure 25)

Figure 25. White totes going to buffe is blocked with error totes in conveyer line (and error station is full).

Given the multiple possibility points this new simple U track would have, it seems this option has a large potential build into it. However, as just shown earlier, this would still leave the conveyer line somewhat vulnerable for the error station fill up problems. The possible problem areas are shown on the Figure 26. Because of this, next chapter discusses on some simple options how to extend the size of the error station conveyer line to give the people working there an extended time buffer to react on possible exception situation.

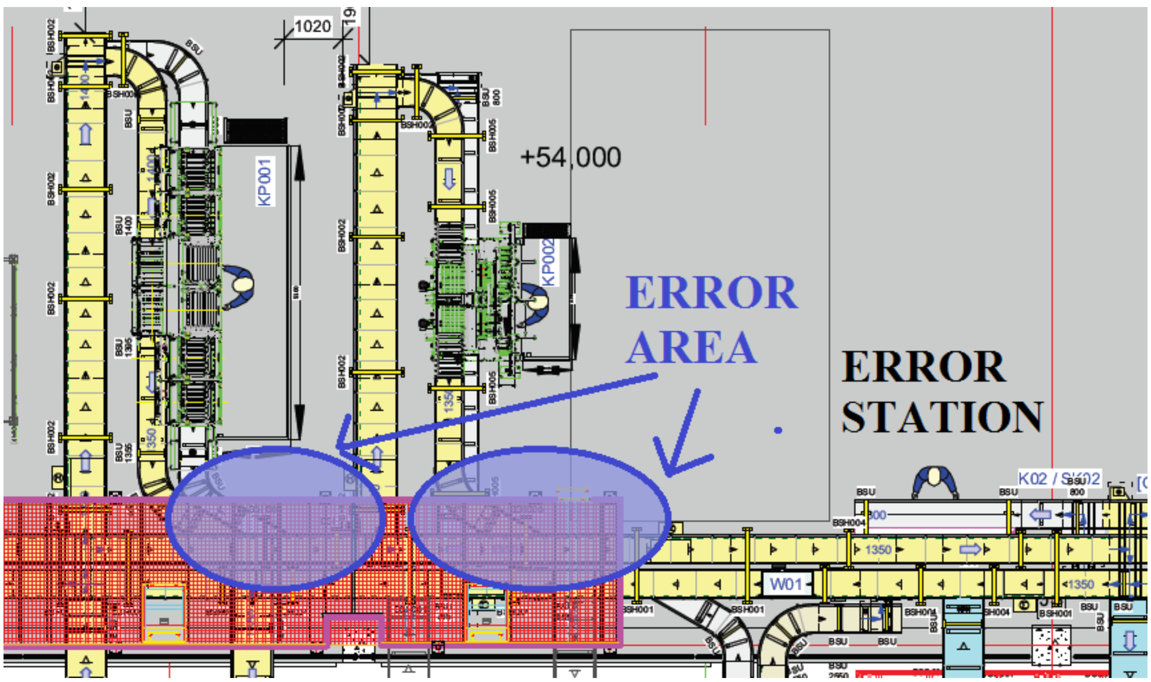


Figure 26. Error area where white picked totes are blocked if error station is full.

5. ERROR STATION DEVELOPMENT WITH NEW LOCATION IDEAS

As it was pointed out in the end of the last chapter, one of the Achilles heel (that might generate a weak point in the process in near future (Kollenscher et al., 2013)) of the second-floor conveyer line is the error station. The current error station has such a short collection line that it can easily be overfilled with a buffer of error totes. This then generates a blocking condition e.g. between picking and packing stations, which is a big problem for system efficiency.

Considering the current situation of the case company, seeking more customers to be included to be served with AS/RS it is more than likely that in ramp up months and after that when the system is asked to output more totes in higher output capacity, the error stations will be a big showstopper for maximum efficiency. There are two simple solutions to this problem. First is to add more people working constantly on error station, but that also means lot of man-hours that are just idling time (waiting for errors or some work on secondary priority stuff). Most likely better option would be to consider possibilities to extent the length of the error station buffer line length. For this, at least few simple solutions should be available.

5.1. Extending the error station conveyer buffer length

In this first option, the error station conveyer starting point stays exactly where it is and also the error handling point and end of the line are exactly in the same positions as they are now. This will make the extension extremely simple from system point of view as from systems point the handling and cross point locations do not change at all. All this is achieved by extending the current error station conveyer line between the starting and end point. The option discussed in here is visualized in below in the Figure 27.

Figure 27. Extension for error station feed buffer conveyer to be built between current start and end points for simplicity.

Depending on the needs of floor space, the cost of extension compared to all the corners and side movement platforms and so on, there is another format available for this sort of extended conveyer line, that would be built almost into the same place, but with little bit different ideology. The difference is that in this another way of building a long and narrow extension, the extension would be straight path almost up until the end of the error station. This would mean that the current error station line could be taken away. Also, there would be a maintenance cap between the line from the picking to packing station and the error station line. In the following Figure 28, one can see a dashed black line in top of the red newly build conveyer extension. The black line is a maintenance bridge that can be turned open to give free and simple access to current conveyer lines.

Figure 28. Another way of building long and narrow extension for some buffer line for the error station conveyer. The line includes a maintenance bridge (black dash line in the picture).

5.2. Zik zak length extension of the error station conveyer to add some buffer

The second option to extend the error station conveyer buffer is built around of idea of making a zik zak line between the start and endpoints of this line. In this case the needed floor space would be more in square format than long and narrow as it was in the first idea. The difference might be important, depending on the use case needs for the future for the floor space that is left to be free. Also, in the second option there might be a challenge on how to get into the middle totes in this line, if that would ever be necessary. The visualization of the zik zak line is presented in the following Figure 29.

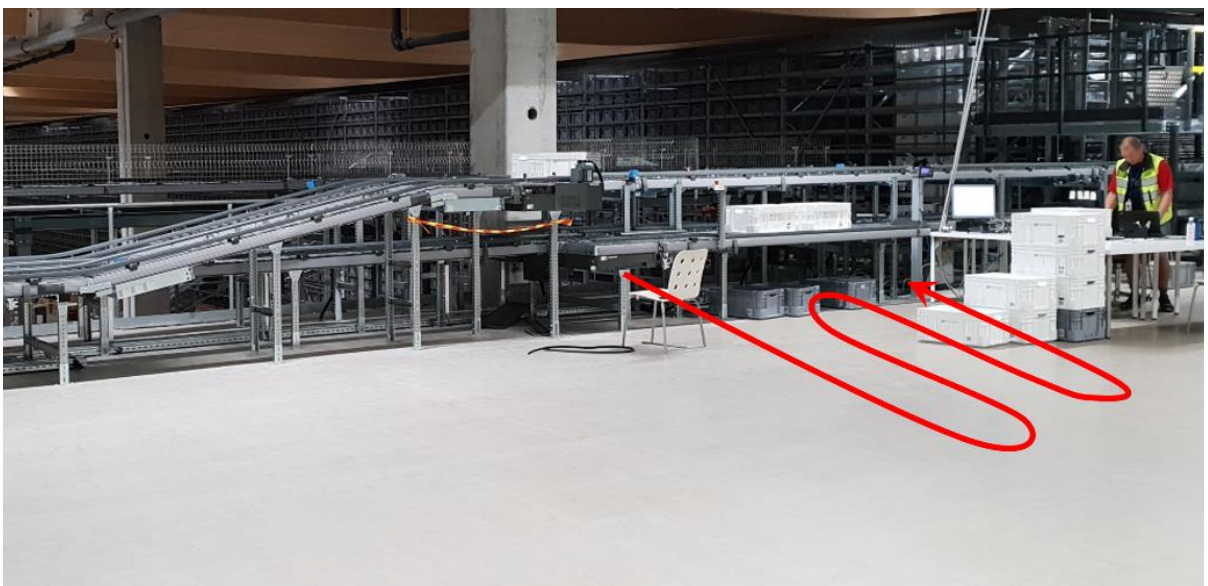


Figure 29. Zik zak line style of extension into error station feed line length.

As conclusion for the extensions, the cost of additional lines, their configuration into current system and the floor space needed should be weighed against all the gains the extension would give the work force, as it will add a lot to time buffer how fast and with what lead times people have to react and fix e.g. picking related errors.

6. CONCLUSIONS

As conclusion, it has been a joy to work with the case company to achieve this university – industry research effort into the context of warehouse operations / flow analysis and case analysis around work process enhancements, related to current and possible future options and directions the operator might want to proceed in future.

In short, this report presents a large-scale analysis of the warehouse performance, especially, in conveyer, AS/RS and tote life cycle context. These analyses do concern e.g. the AS/RS performance data, the movement paths of totes and the times it takes for them to get from A to B, including buffer and error stations analysis. As for further study, we would suggest a realistic visualisations of possible different e.g. packing station scenario analysis or looking different options for enhancing the use of space in impound and out-pound areas. For example following the research lines of (Lindskog et al., 2016)

As general conclusions, we would like to recommend any and all companies to try their best to get in this sort of collaboration level with university research, as what the case company has achieved in here. This practice is well known vehicle to enhance innovation through knowledge exchange (Ankrah & AL-Tabbaa, 2015), as it was also the case in here, with this company. Their active participation to research work has helped academics to grow in knowledge, which helps the science to go forward in this systems and automated operations research field, in the same time when we as university representatives can contribute to practical work life too.

From the university point of view, it is a privilege to be able to work in this sort of deep collaboration with knowledgeable industry people, who definitely do not have too easy times nowadays, within the ever-tightening customer demands in logistics sector. The collaboration made it possible for us to use academic knowledge and apply that into the practical RDI work to achieve deeper understanding about the different systematic analysis means the collaboration could teach for both parties.

REFERENCES

Ankrah, S., AL-Tabbaa, O., 2015, Universities–industry collaboration: A systematic review, Scandinavian Journal of Management, Vol. 31, Iss. 3, pp. 387-408

Happonen, A., Stepanov, A., Hirvimäki, M. et al. (2015), Art-technology collaboration and motivation sources in technologically supported artwork buildup project, Physics Procedia, Vol. 78, pp. 407-414, doi: 10.1016/j.phpro.2015.11.055

Happonen, A., Minashkina, D. (2018), Ideas and experiences from university industry collaboration: Hackathons, Code Camps and citizen participation, LUT Scientific and Expertise Publications report 86, ISSN: 2243-3384, pp. 1-21, doi: 10.13140/rg.2.2.29690.44480

Heragu, S.S., Cai, X., Krishnamurthy, A., Malmborg, C.J., 2011, Analytical models for analysis of automated warehouse material handling systems, International Journal of Production Research, Vol. 49, Iss. 22, pp. 6833-6861, doi: 10.1080/00207543.2010.518994

Knapp. (2018) Knapp Storage websites. [online document]. [Accessed 05 December 2018]. Available at: https://www.knapp.com/en/solutions/technologies/storage/

Kollenscher, E., Ronen, B., Coman, A., 2013, Achilles' heel strategy: identifying and leveraging a competitor's weakest point, International Journal of Production Research, Vol. 52, Iss. 3, pp. 651-661, doi: 10.1080/00207543.2013.825746

Lindskog, E., Vallhagen, J., Johansson, B., 2016, Production system redesign using realistic visualisation, International Journal of Production Research, Vol. 55, Iss. 3, pp. 858-869, doi: 10.1080/00207543.2016.121

Postnord. (2017) E-commerce in the Nordics 2017. [online]. [Acc. 10 April 2018]. Available at: https://www.postnord.com/globalassets/global/english/document/publications/2017/e-commerce-in-the-nordics-2017.pdf

Rantala, J., Happonen, A. (2012), Success factors of collaborative product development in production networks, 17th International Symposium on Logistics (ISL 2012), Cape Town, South Africa, ISBN: 978 085358 284 7, pp. 120-127, doi: http://doi.org/10.5281/zenodo.3370264

Salmela, E., Happonen, A., Vainio, V. (2007), Strategic Collaboration in Supply Chain of Technical Wholesale Items. Case Mercantile Ltd., ICMC 2007, 3-4.12.2007, IMT Ghaziabad, India, ISBN: 979-81-8424-262-0, pp. 349–355, doi: 10.5281/zenodo.3373627

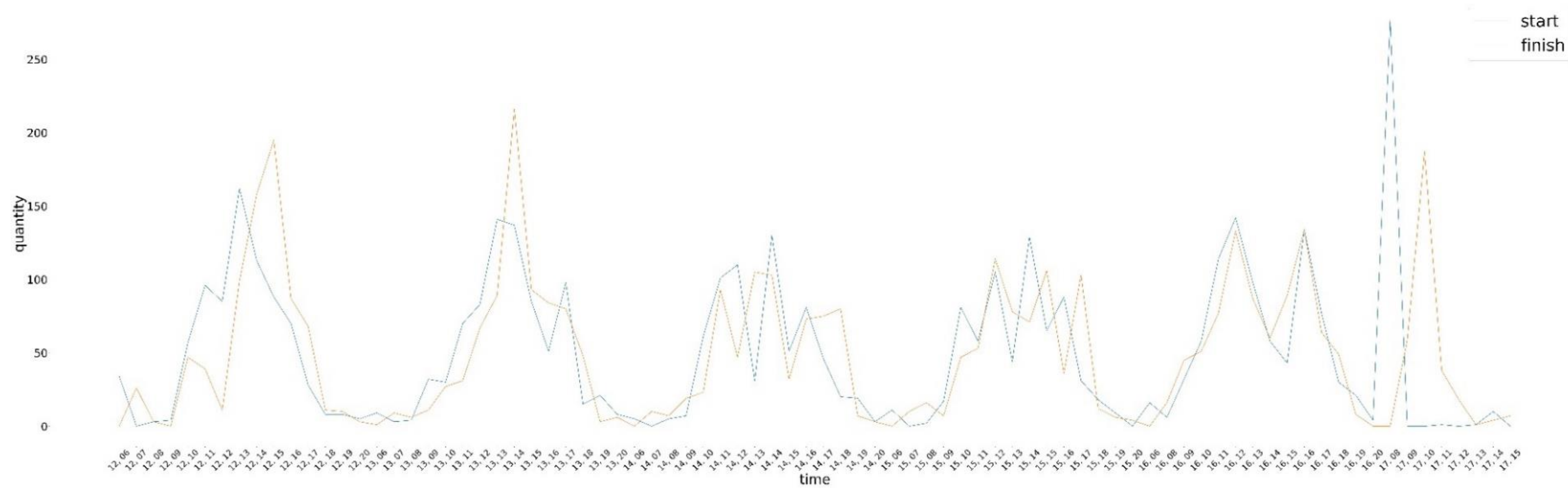
Salmela, E., Happonen, A., Huiskonen, J. (2011), Best Collaboration Practices in Supply Chain of Technical Wholesale Items, International Journal of Collaborative Enterprise, Vol. 2, No. 1, pp. 16-38, doi: 10.1504/IJCENT.2011.040663

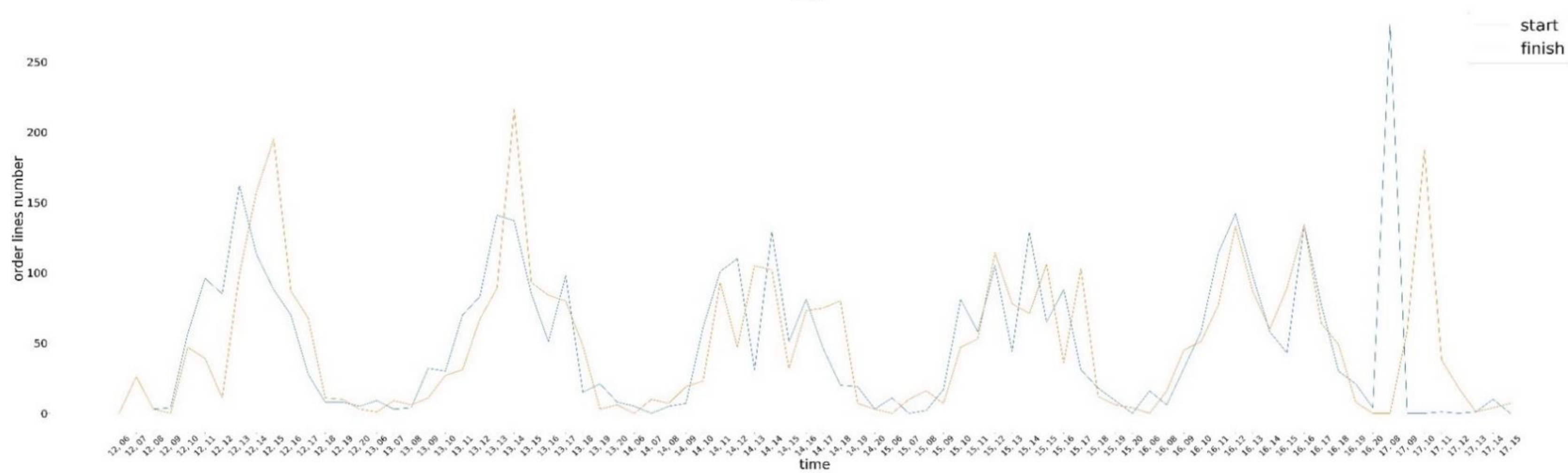
Salmela, E., Santos, C., Happonen, A. (2013), Formalization of Front End Innovation in Supply Network Collaboration, International Journal of Innovation and Regional Development, Vol. 5, No. 1, pp. 91-111, doi: 10.1504/IJIRD.2013.052510

Yao, J.M., 2015, Supply chain resources integration optimisation in B2C online shopping, International Journal of Production Research, Vol. 55, Iss. 17, pp. 5079-5094, doi: 10.1080/00207543.2015.1074298

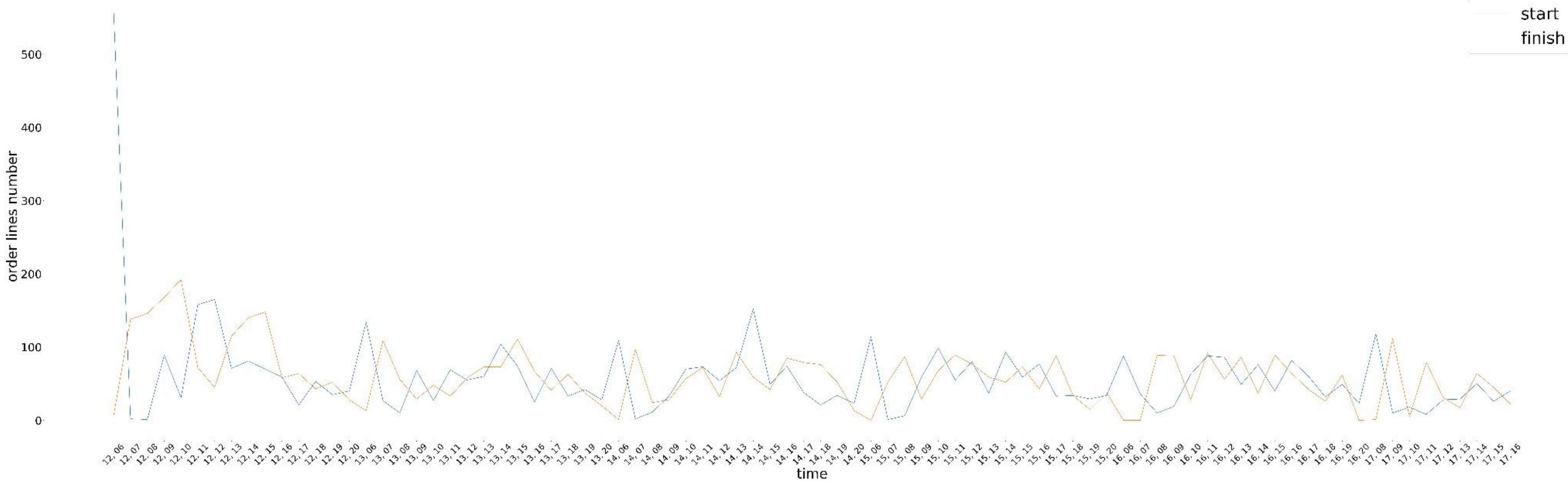
APPENDIXES

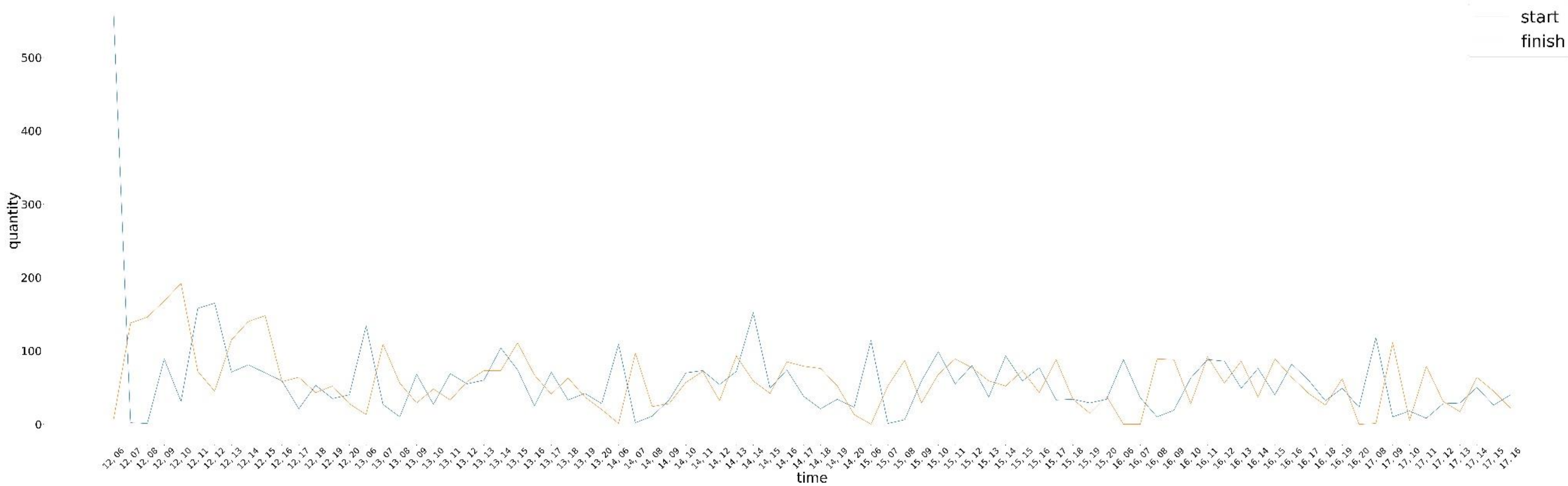
Appendix 1. B2B orders type-March (week 11)



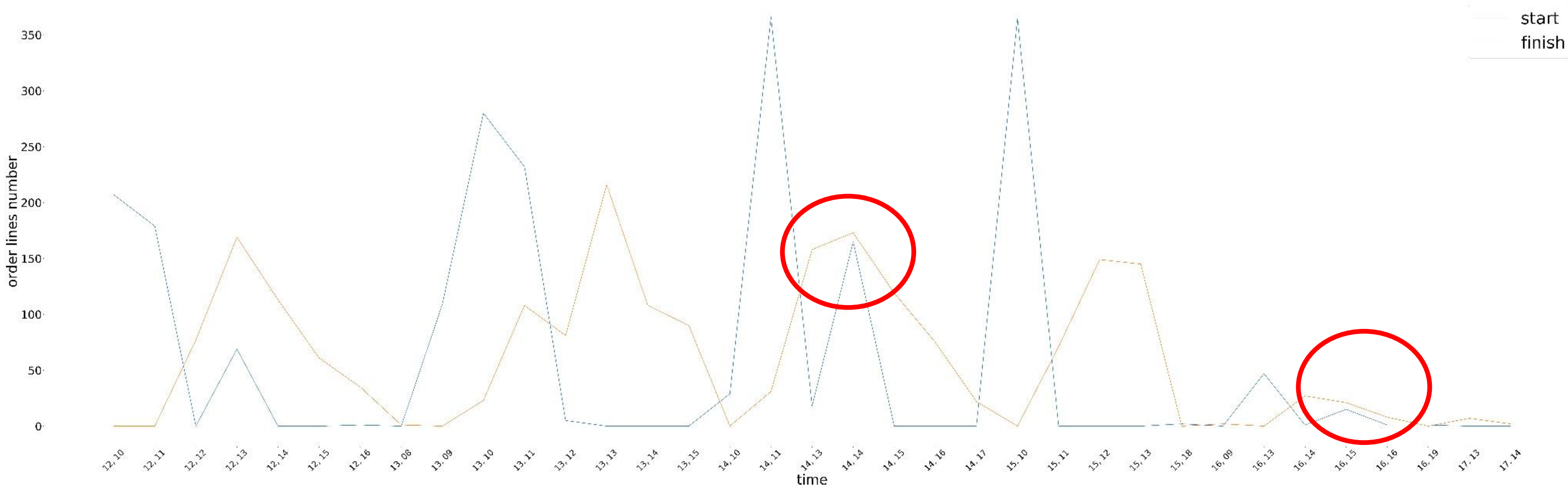


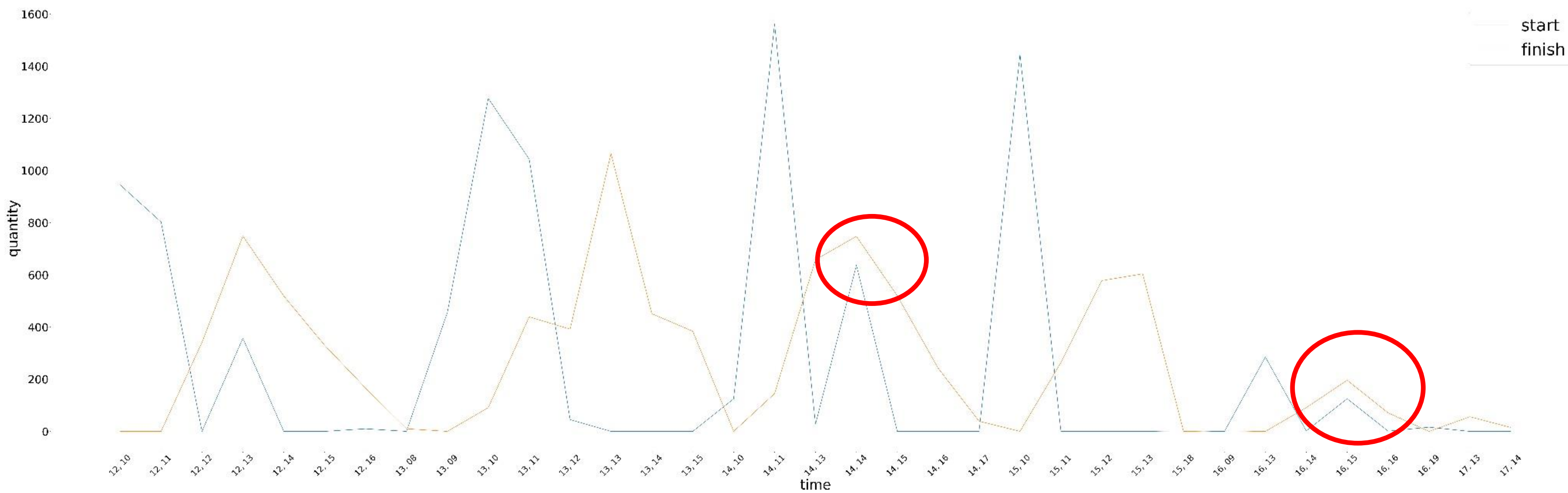
Appendix 2. B2C orders type-March (week 11)



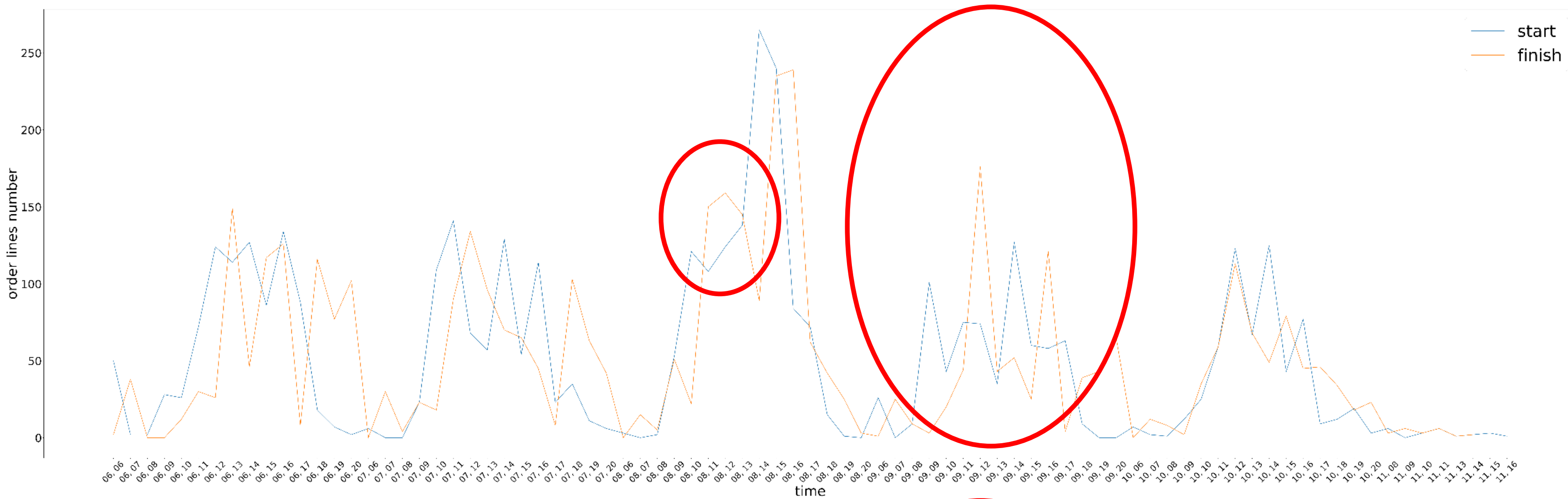


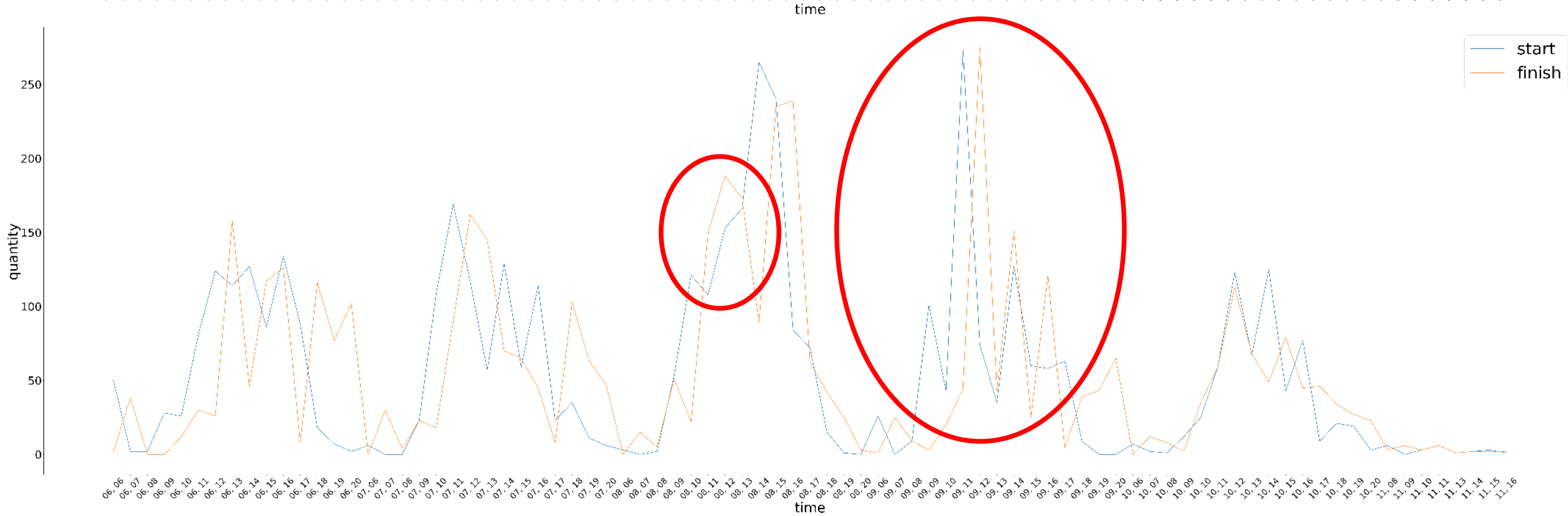
Appendix 3. Shop replenishment orders type-March (week 11)



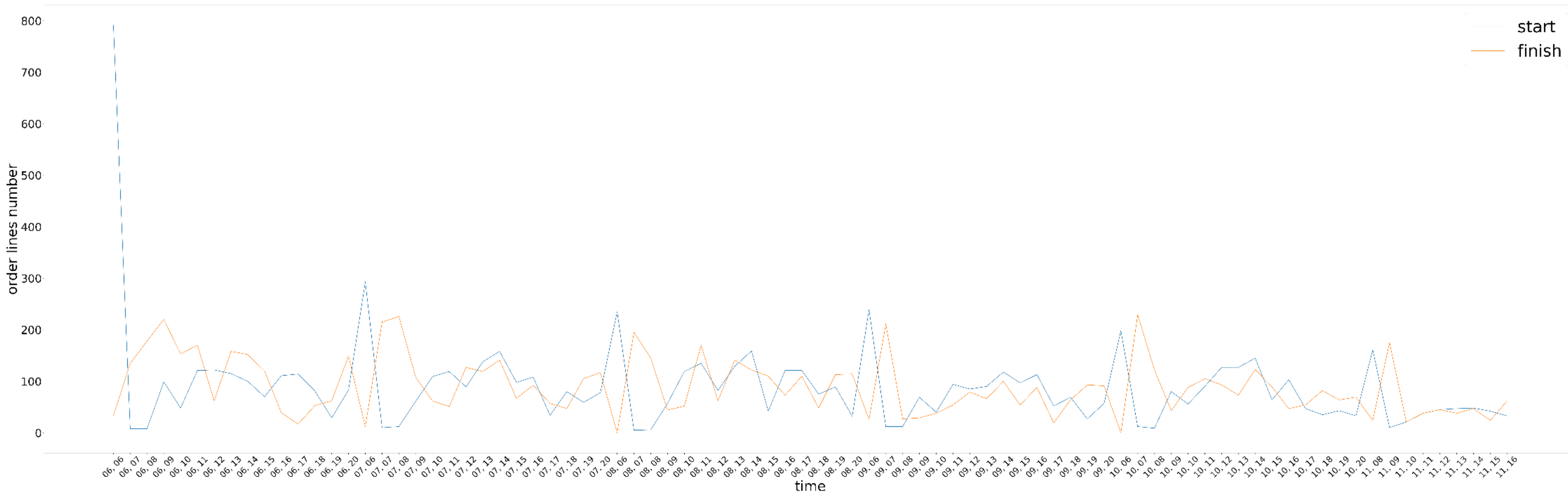


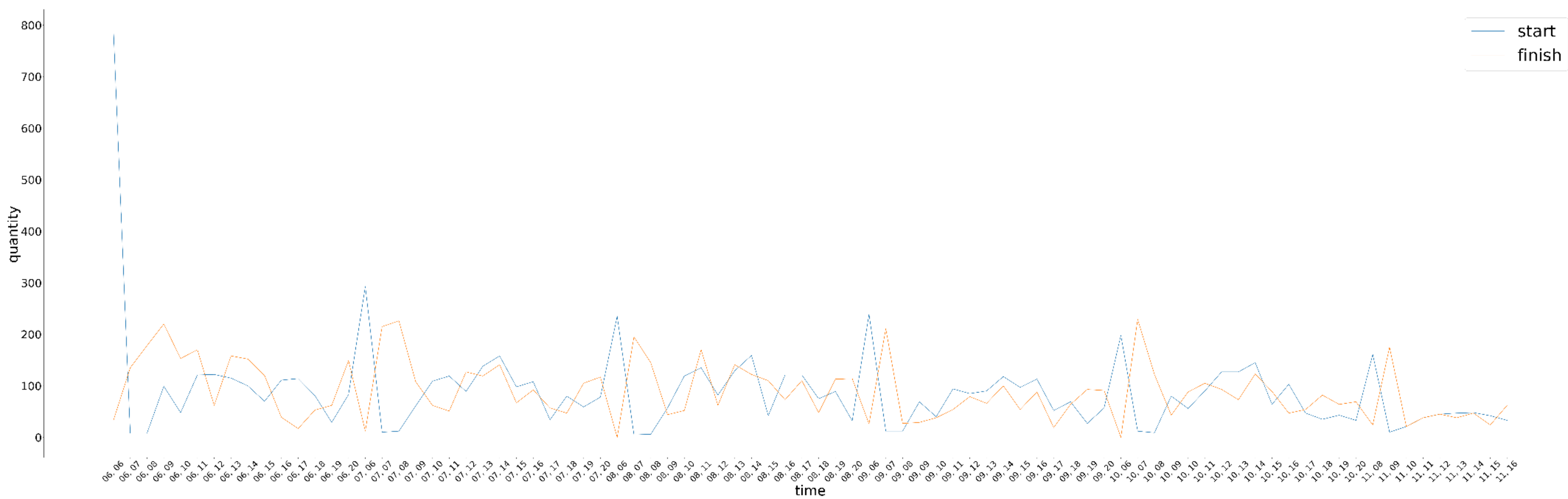
Appendix 4. B2B orders type-August (week 32)





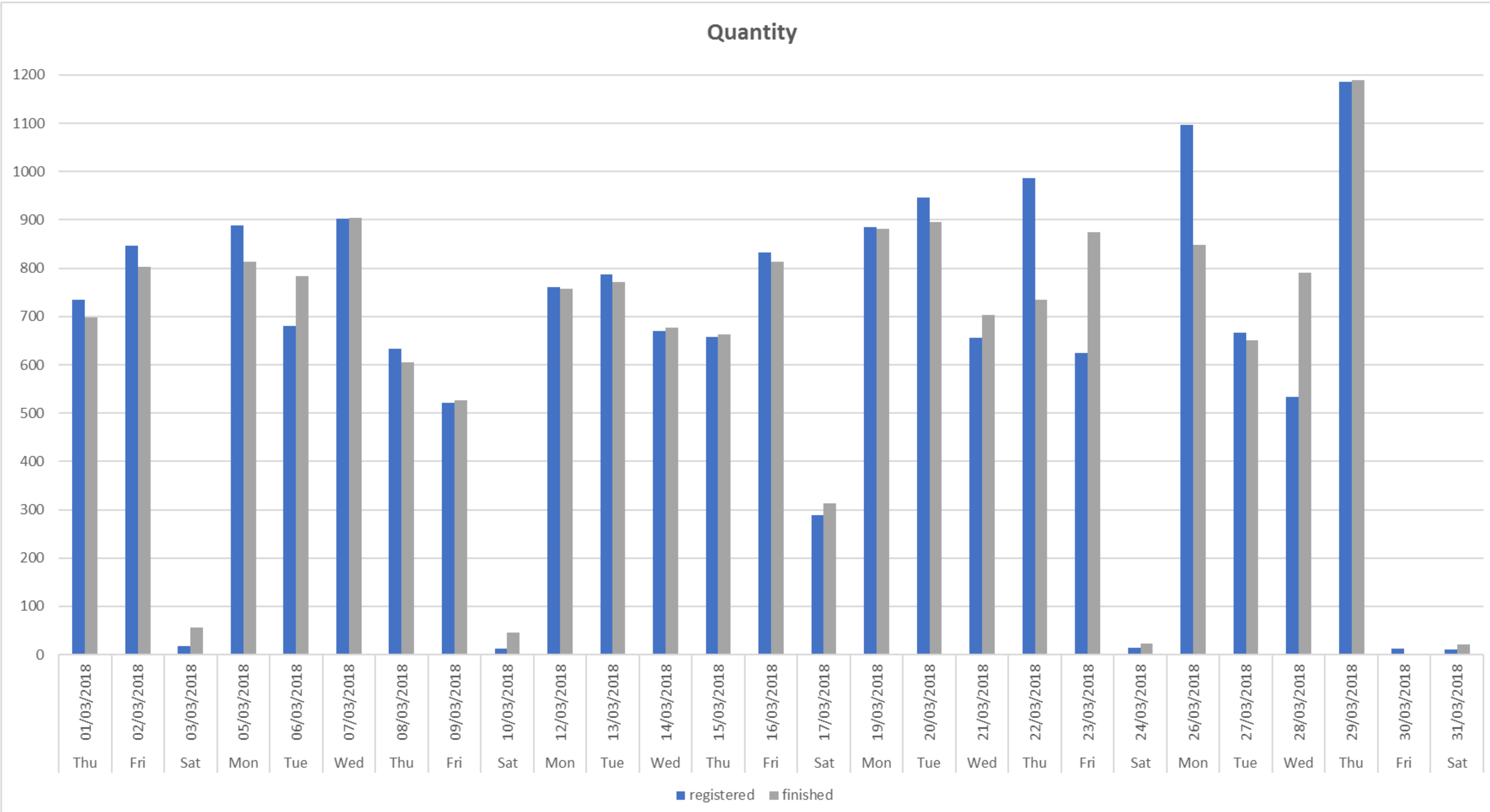
Appendix 5. B2C orders type-August (week 32)



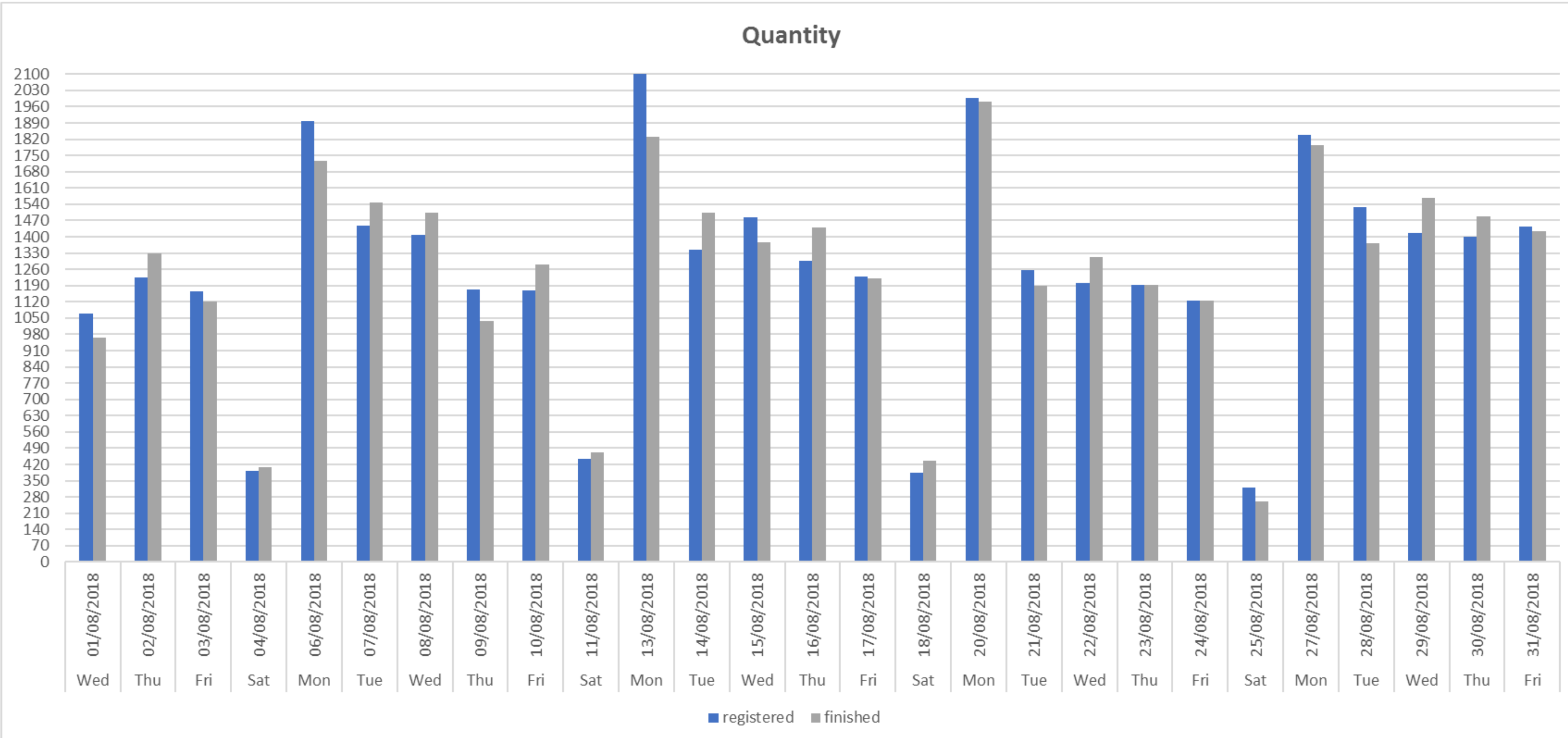


Appendix 6. Shop replenishment orders type-August (week 32)

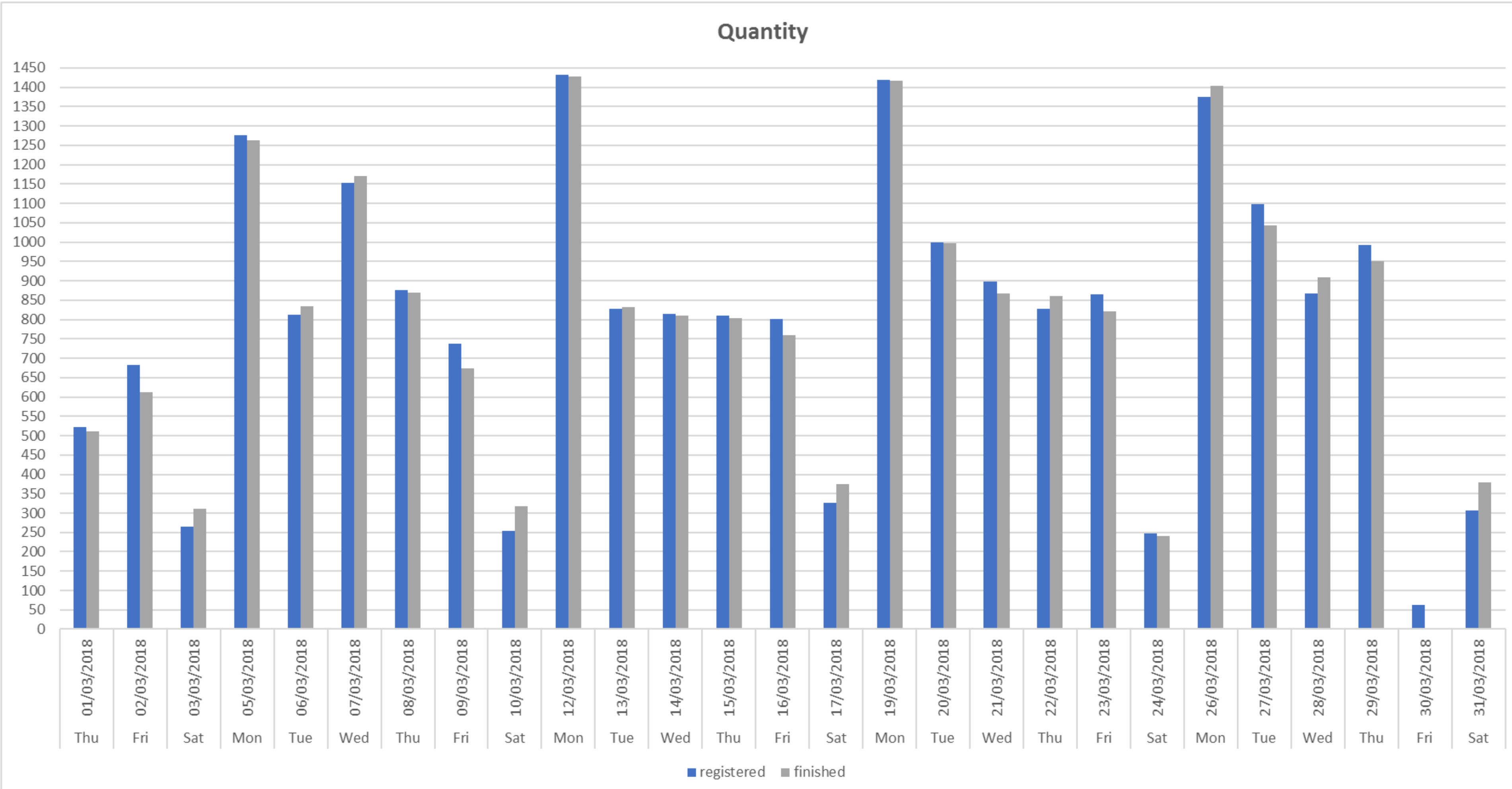
Appendix 7. March B2C orders quantity fluctuation analysis



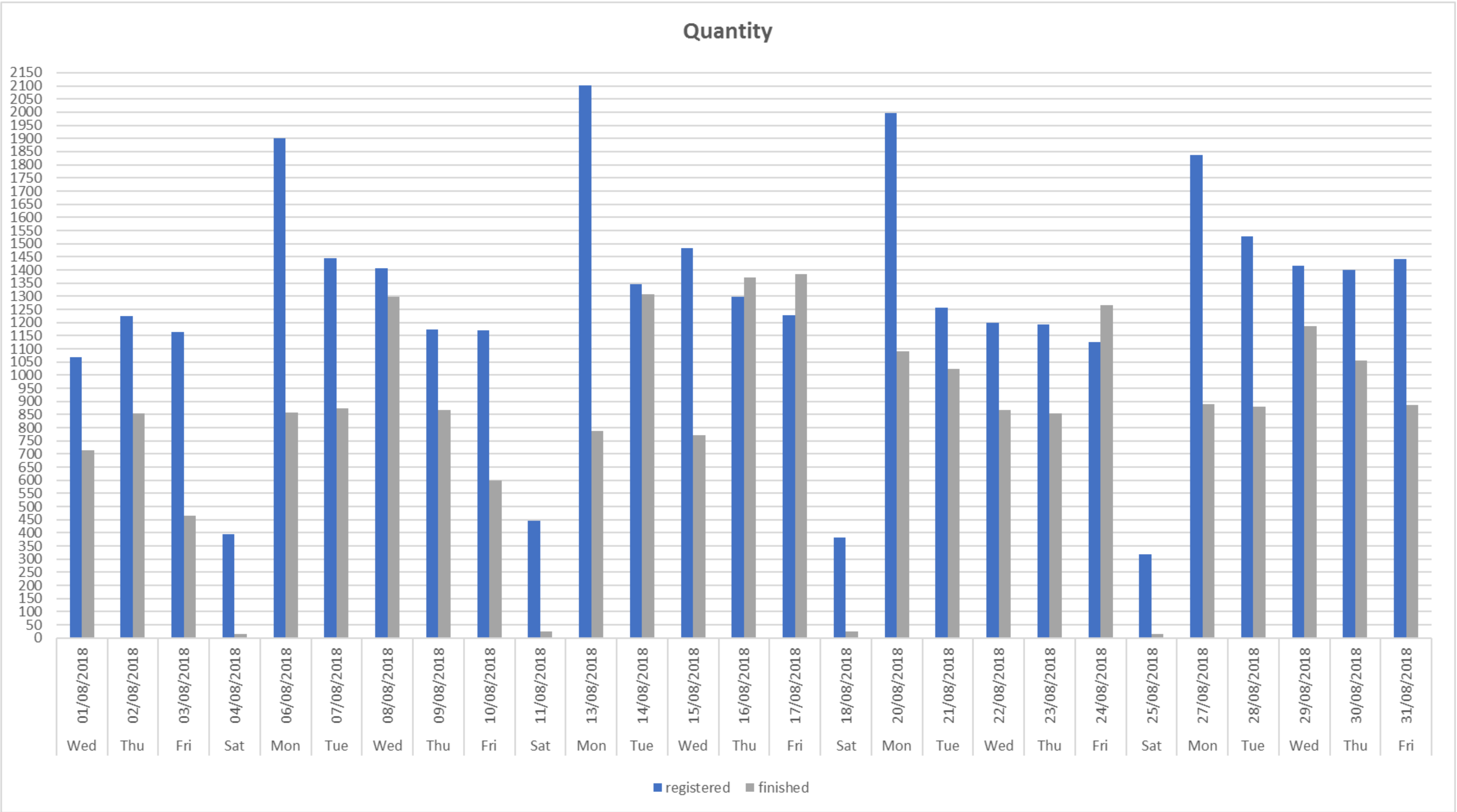
Appendix 8. August B2C orders quantity fluctuation analysis



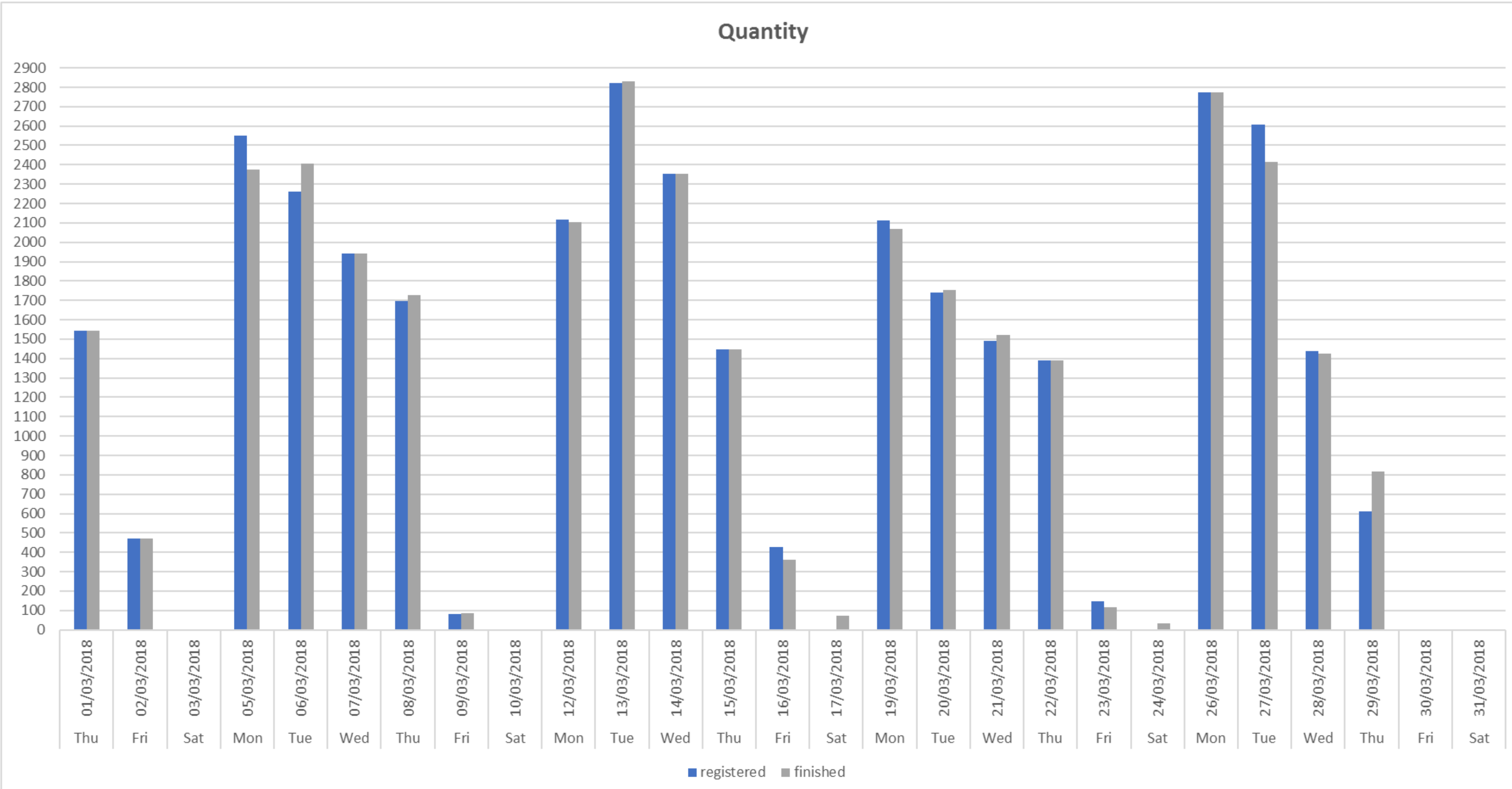
Appendix 9. March B2B orders quantity fluctuation analysis



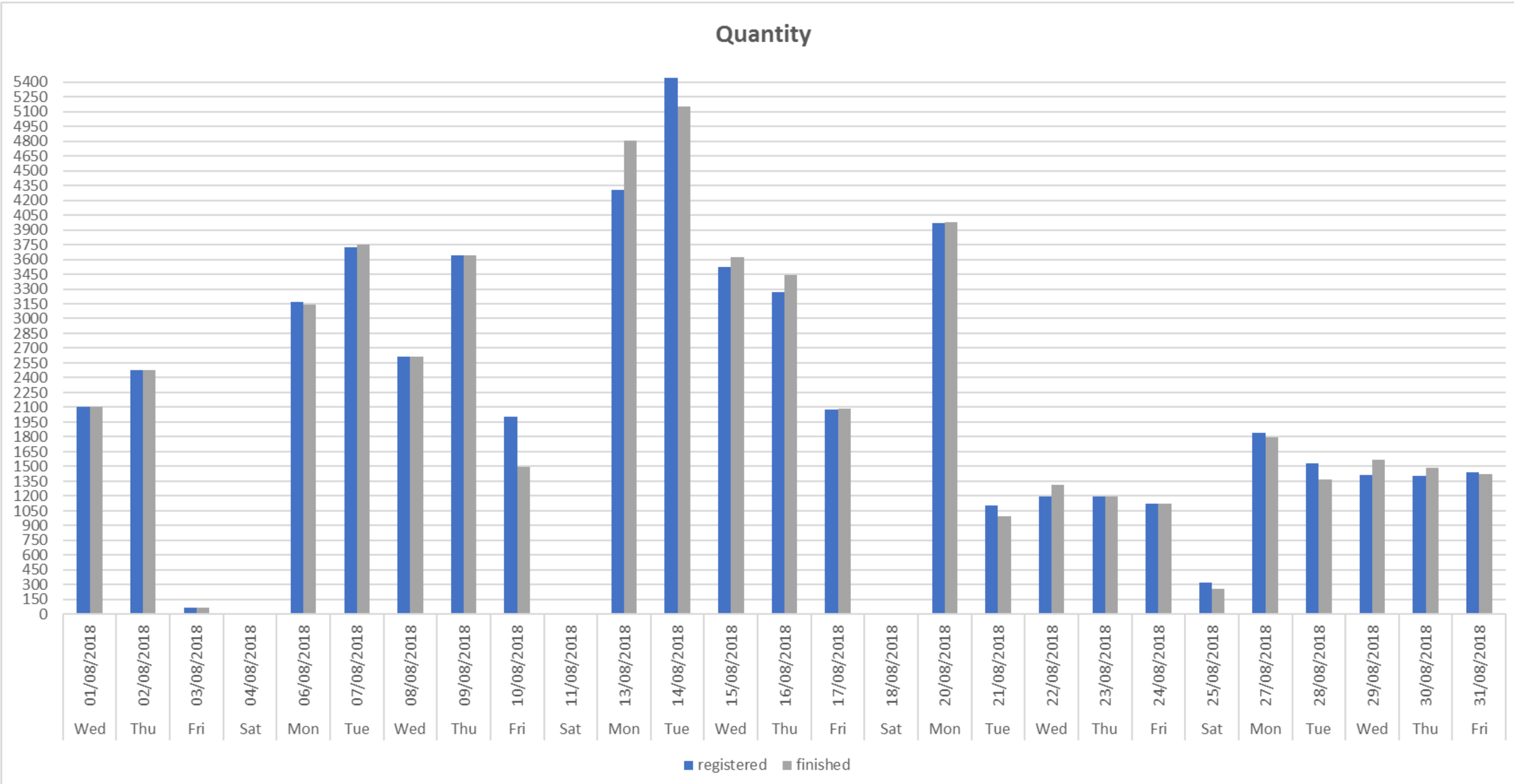
Appendix 10. August B2B orders quantity fluctuation analysis



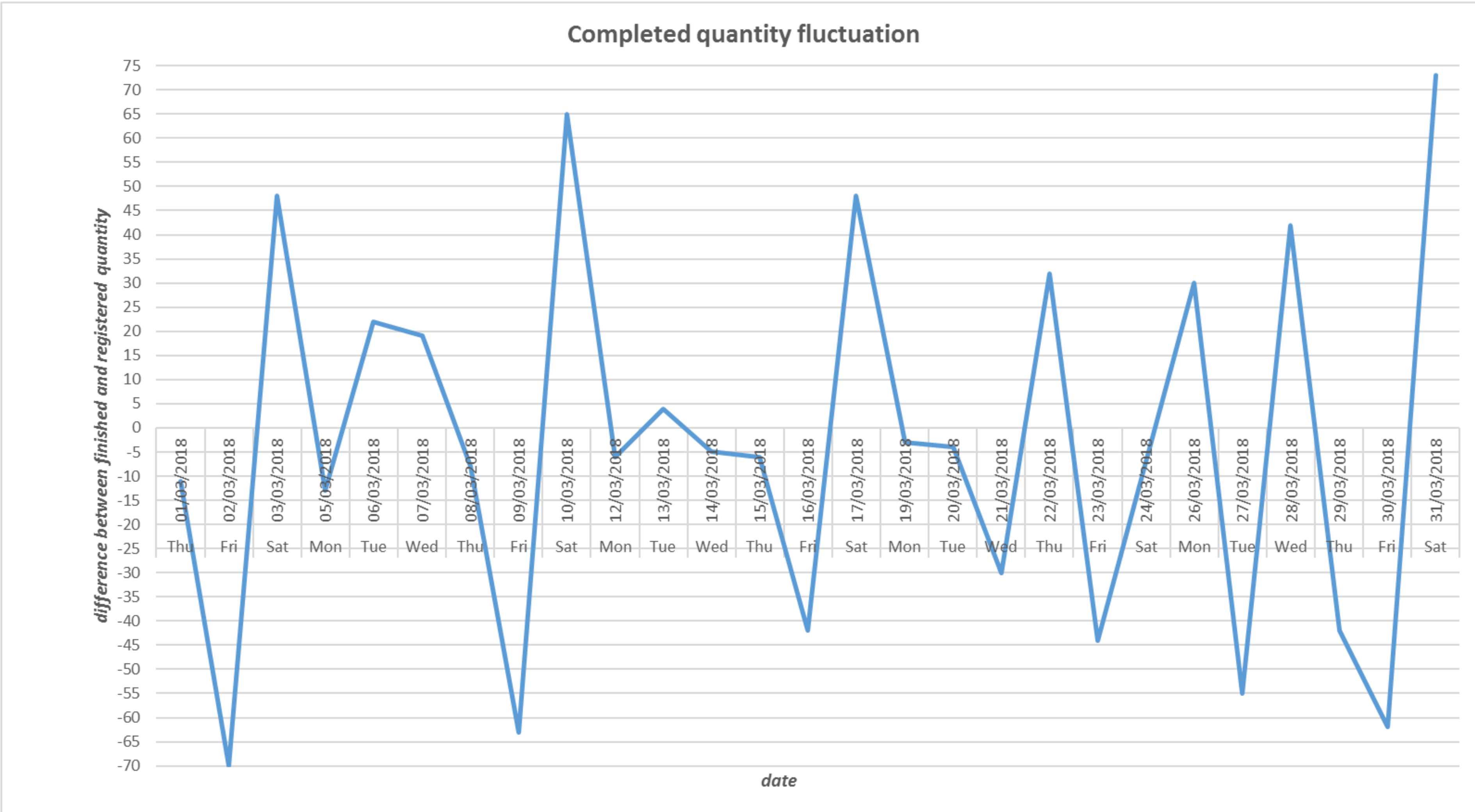
Appendix 11. March Shop replenishment orders quantity fluctuation analysis



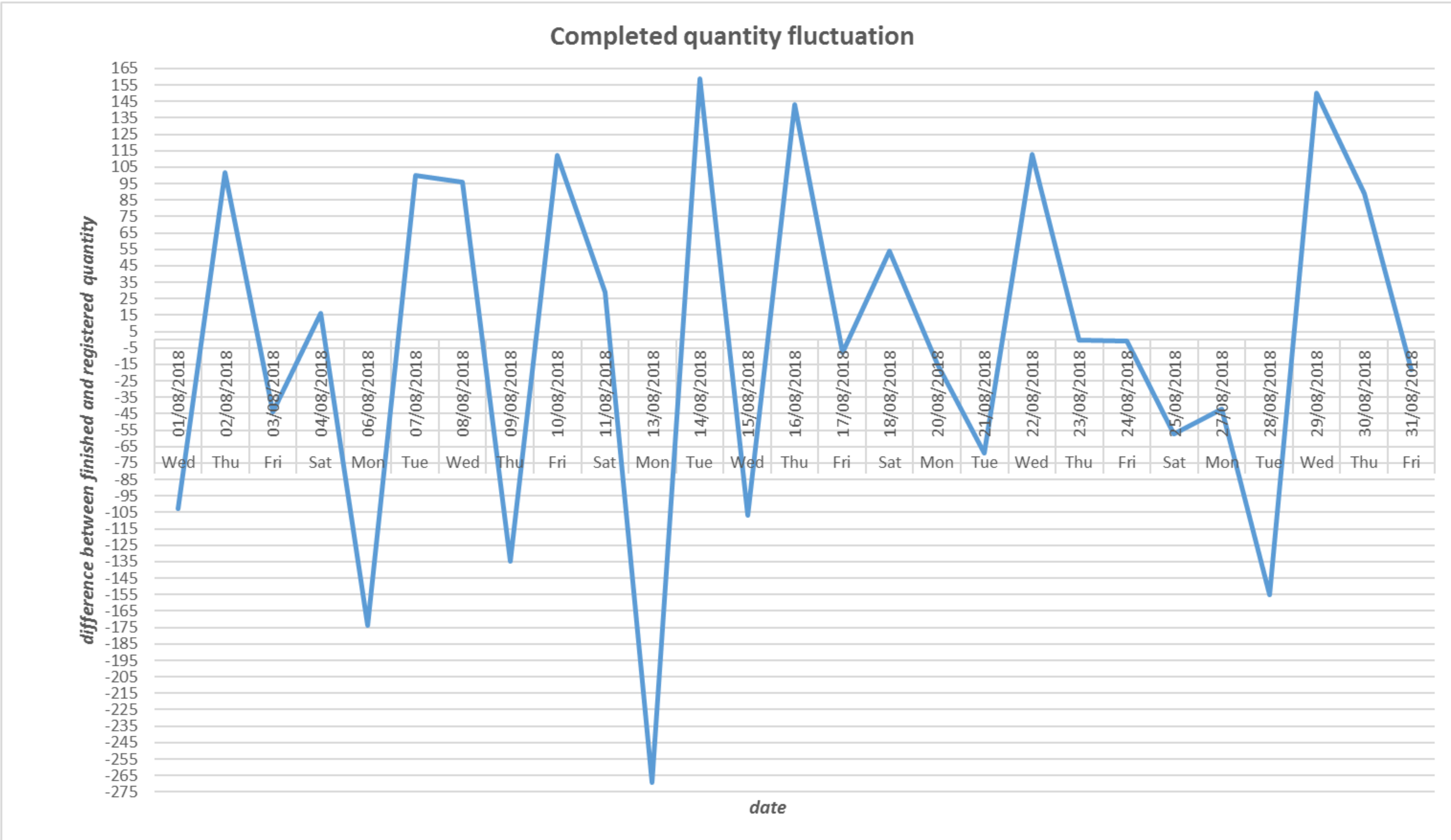
Appendix 12. August Shop replenishment orders quantity fluctuation analysis



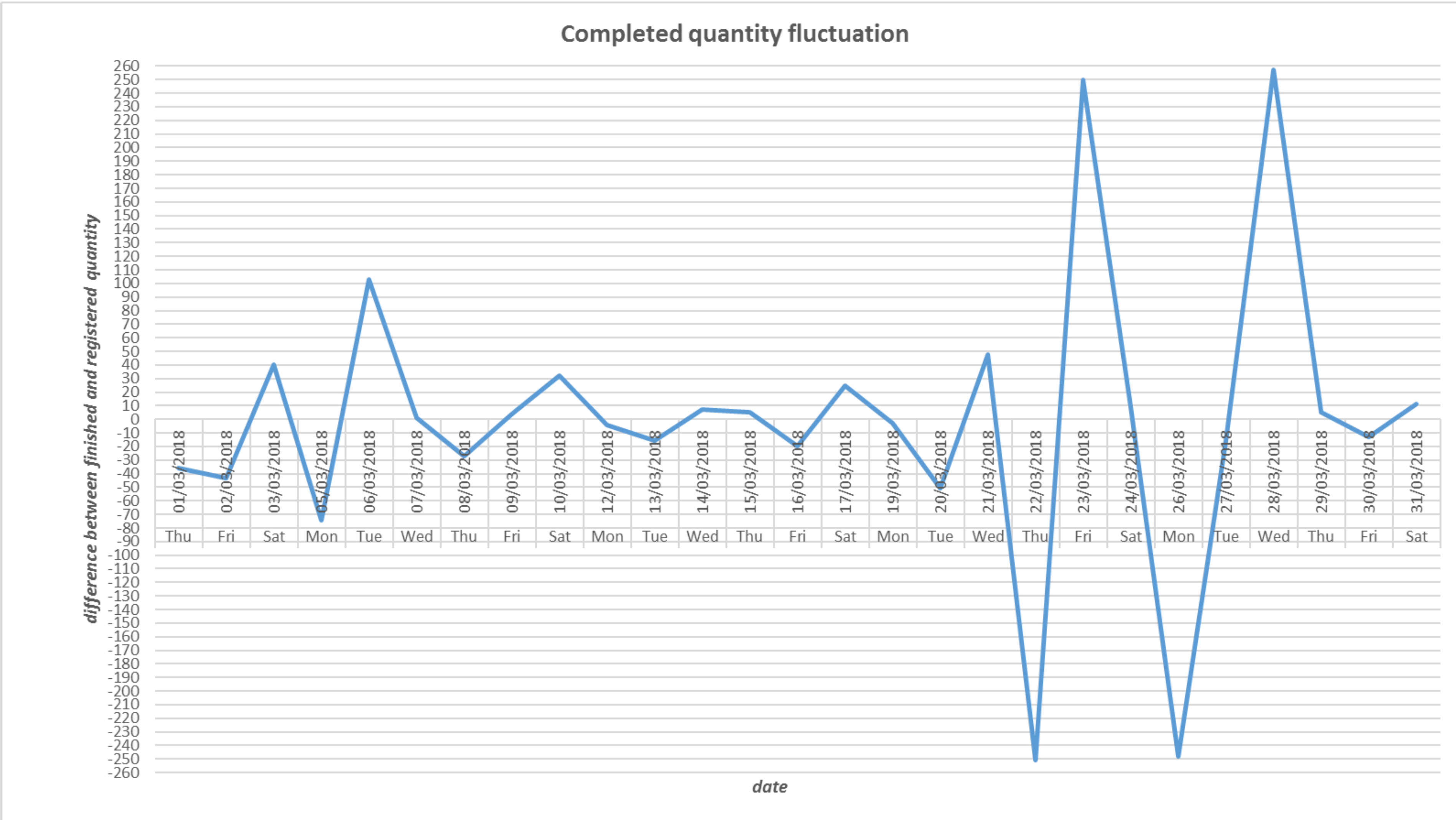
Appendix 13. March not completed B2C orders quantity fluctuation analysis



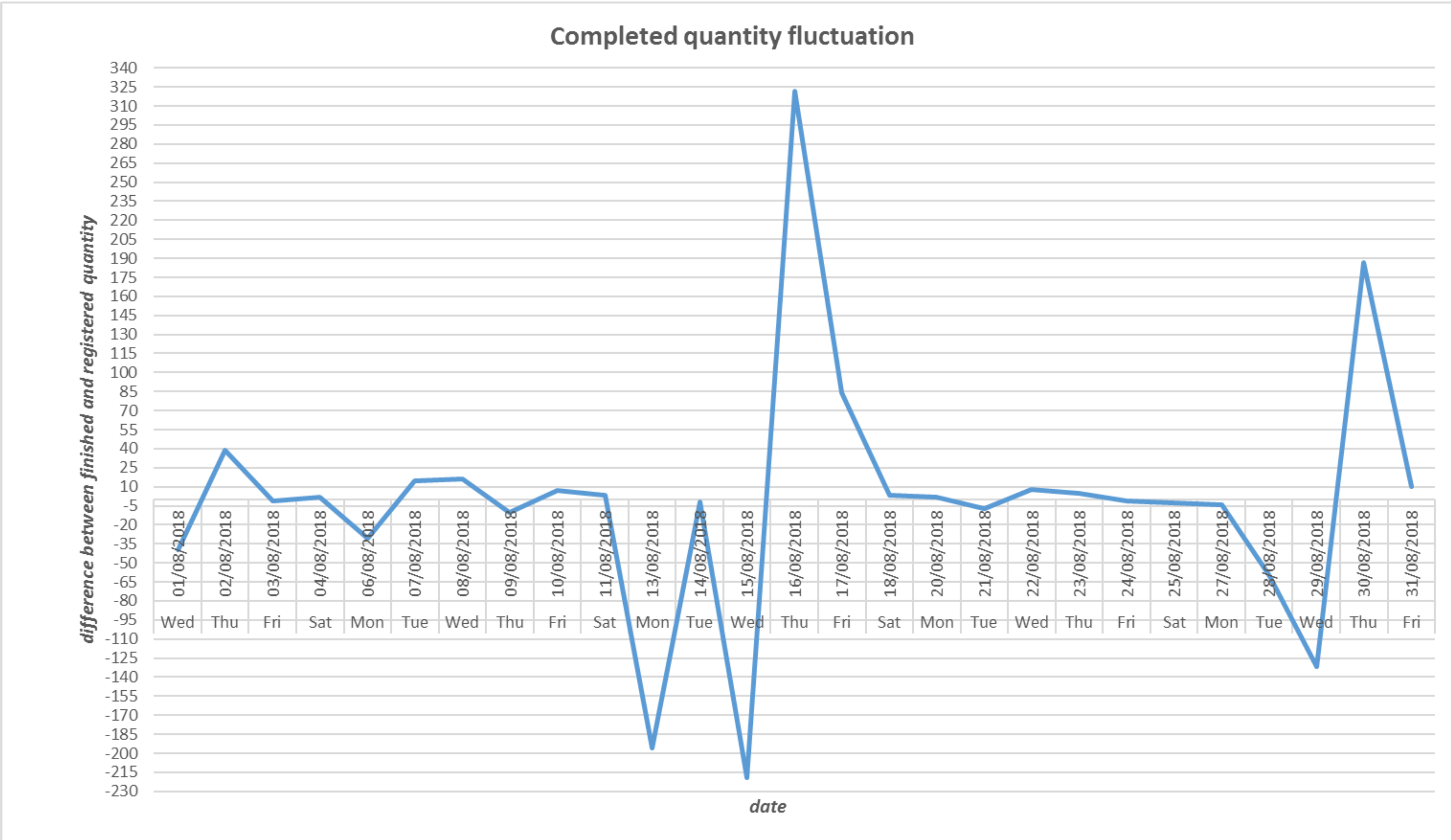
Appendix 14. August not completed B2C orders quantity fluctuation analysis



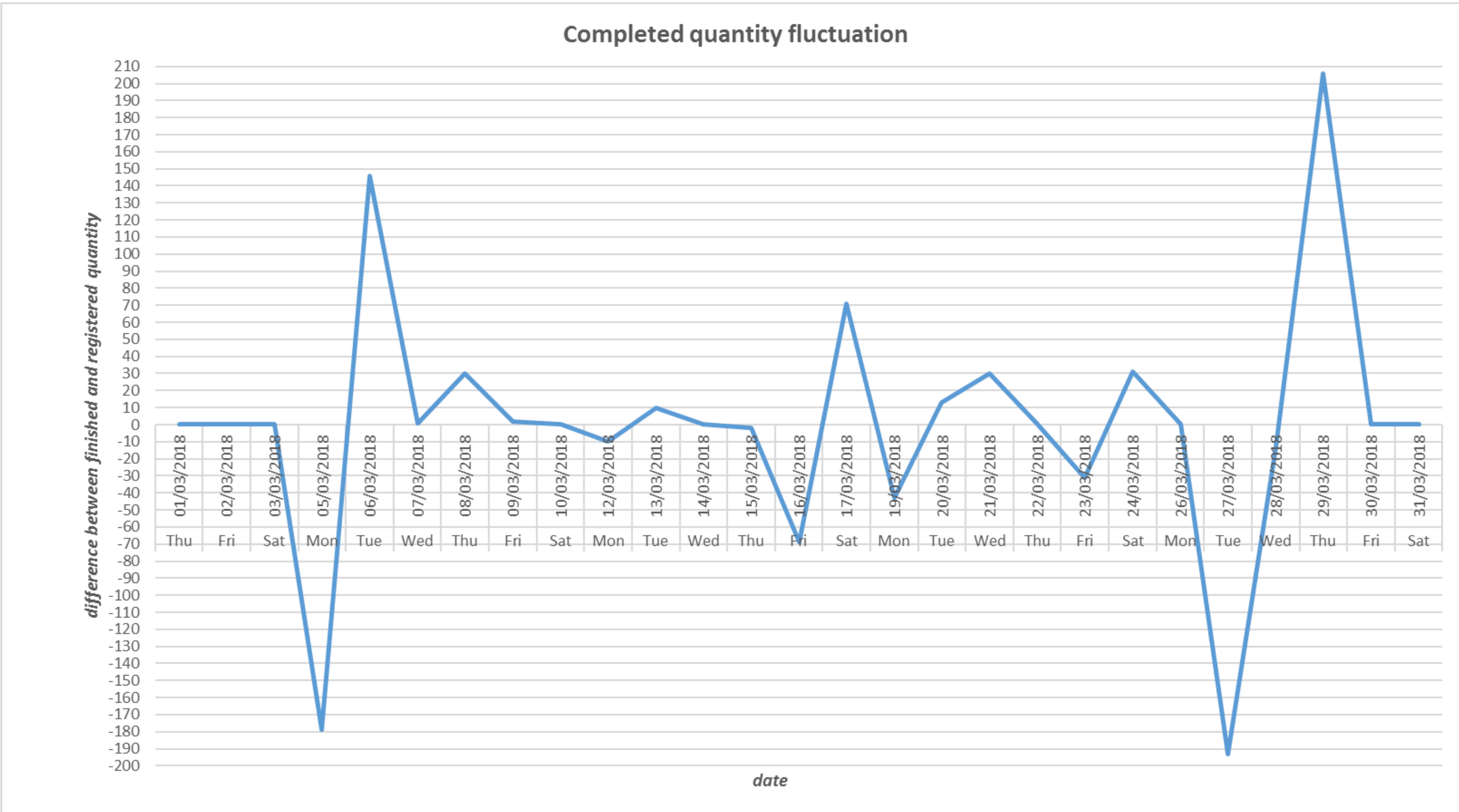
Appendix 15. March not completed B2B orders quantity fluctuation analysis



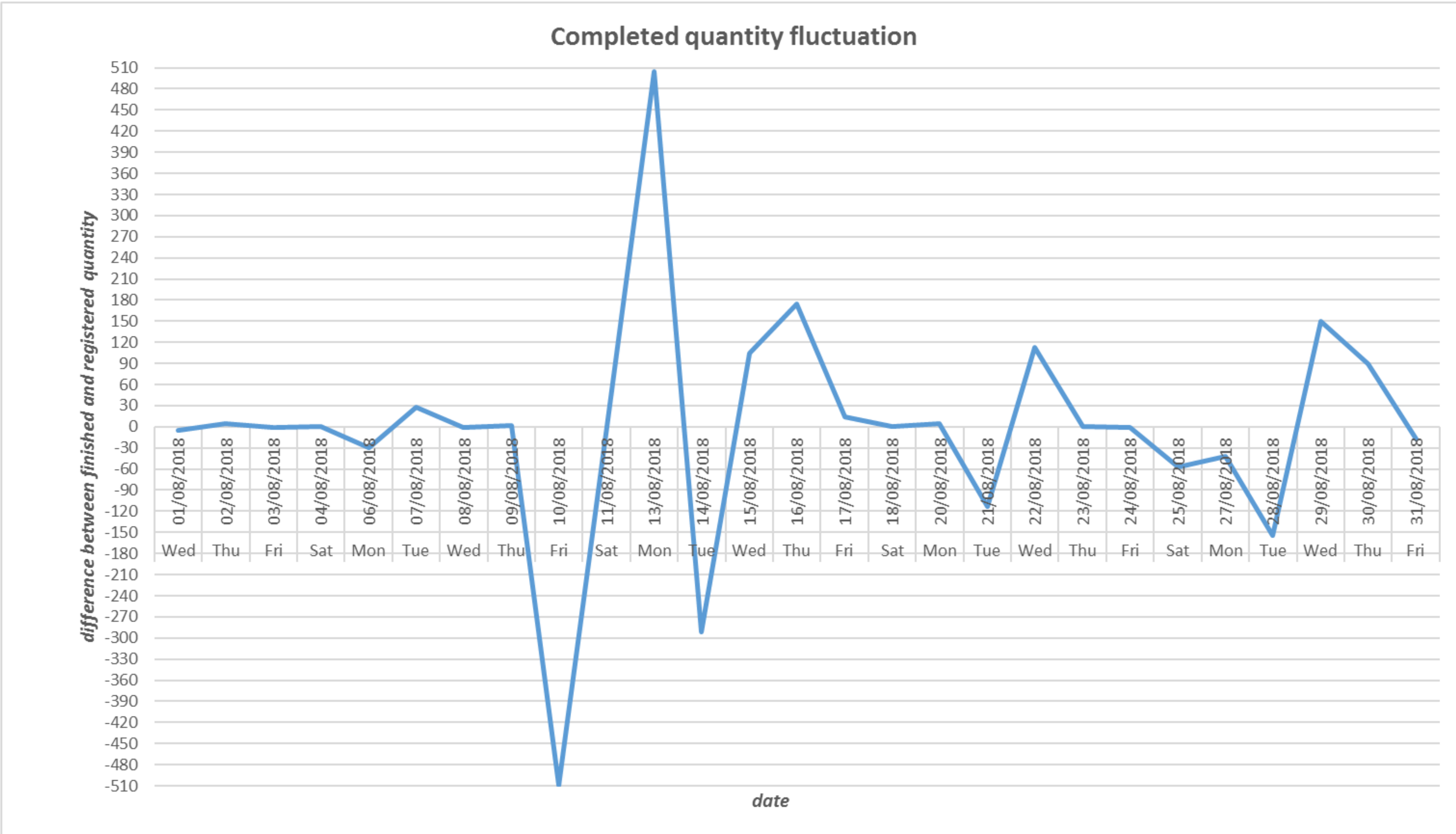
Appendix 16. August not completed B2B orders quantity fluctuation analysis



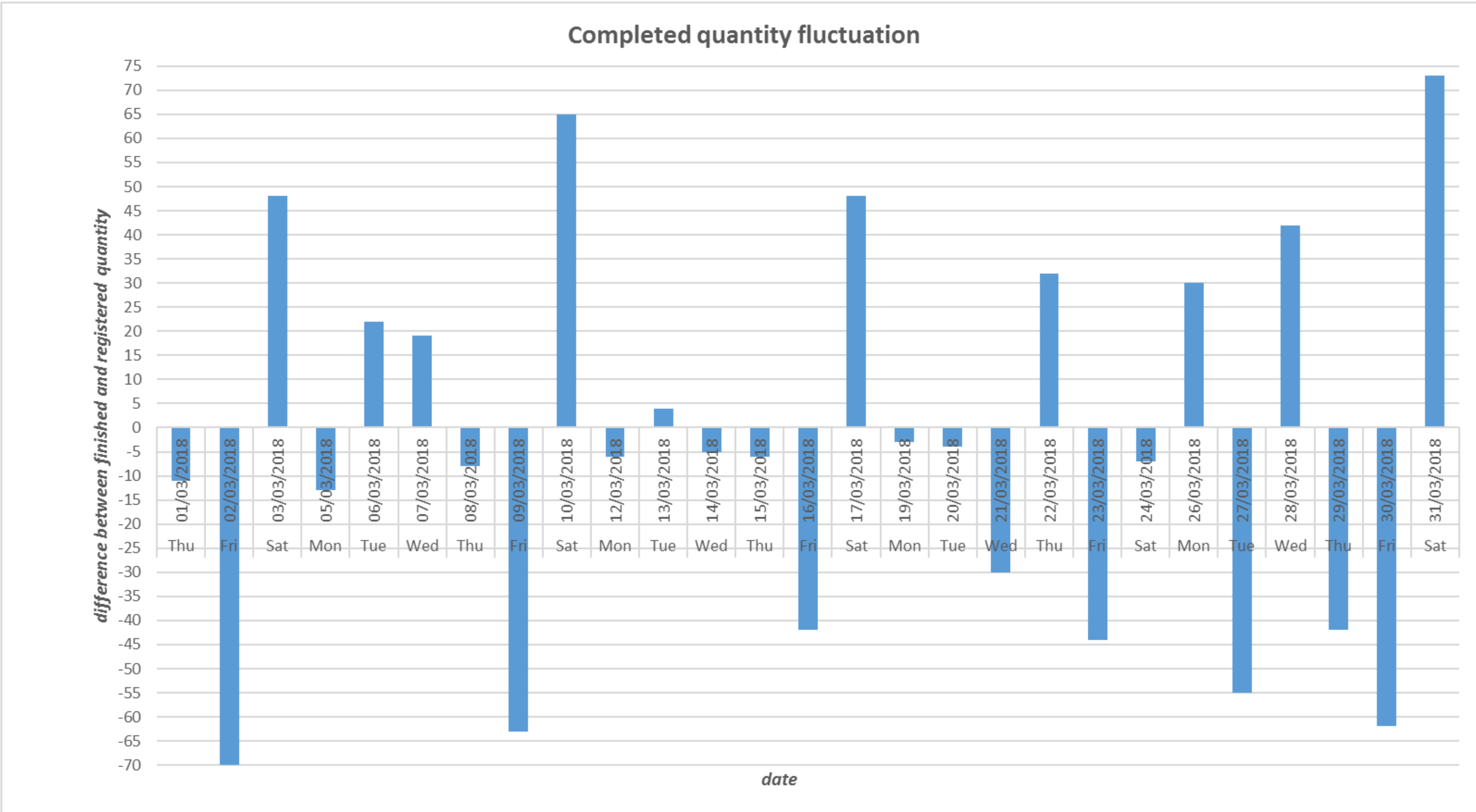
Appendix 17. March not completed Shop replenishment orders quantity fluctuation analysis



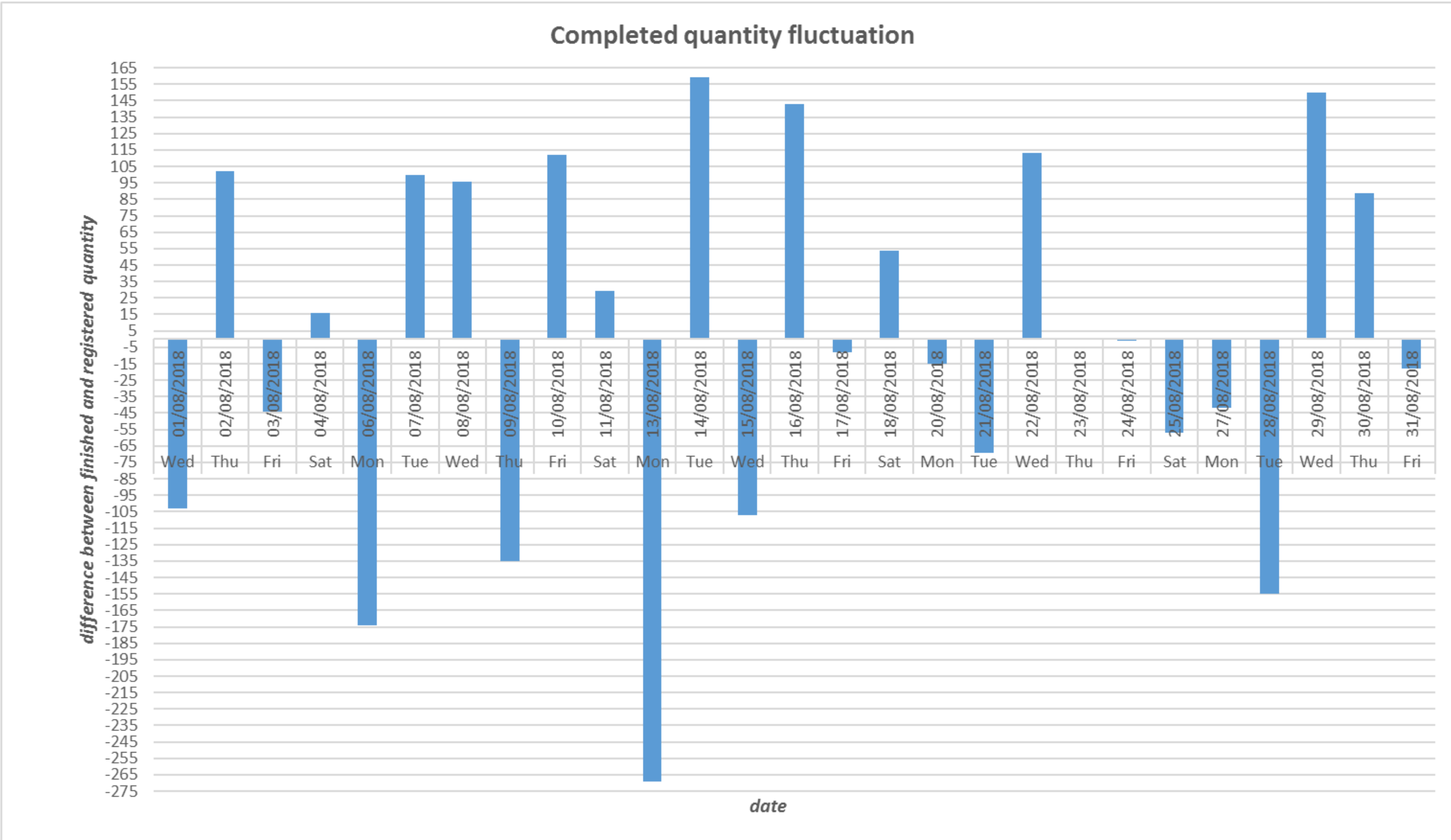
Appendix 18. August not completed Shop replenishment orders quantity fluctuation analysis



Appendix 19. March not completed B2C orders quantity fluctuation analysis



Appendix 20. August not completed B2C orders quantity fluctuation analysis



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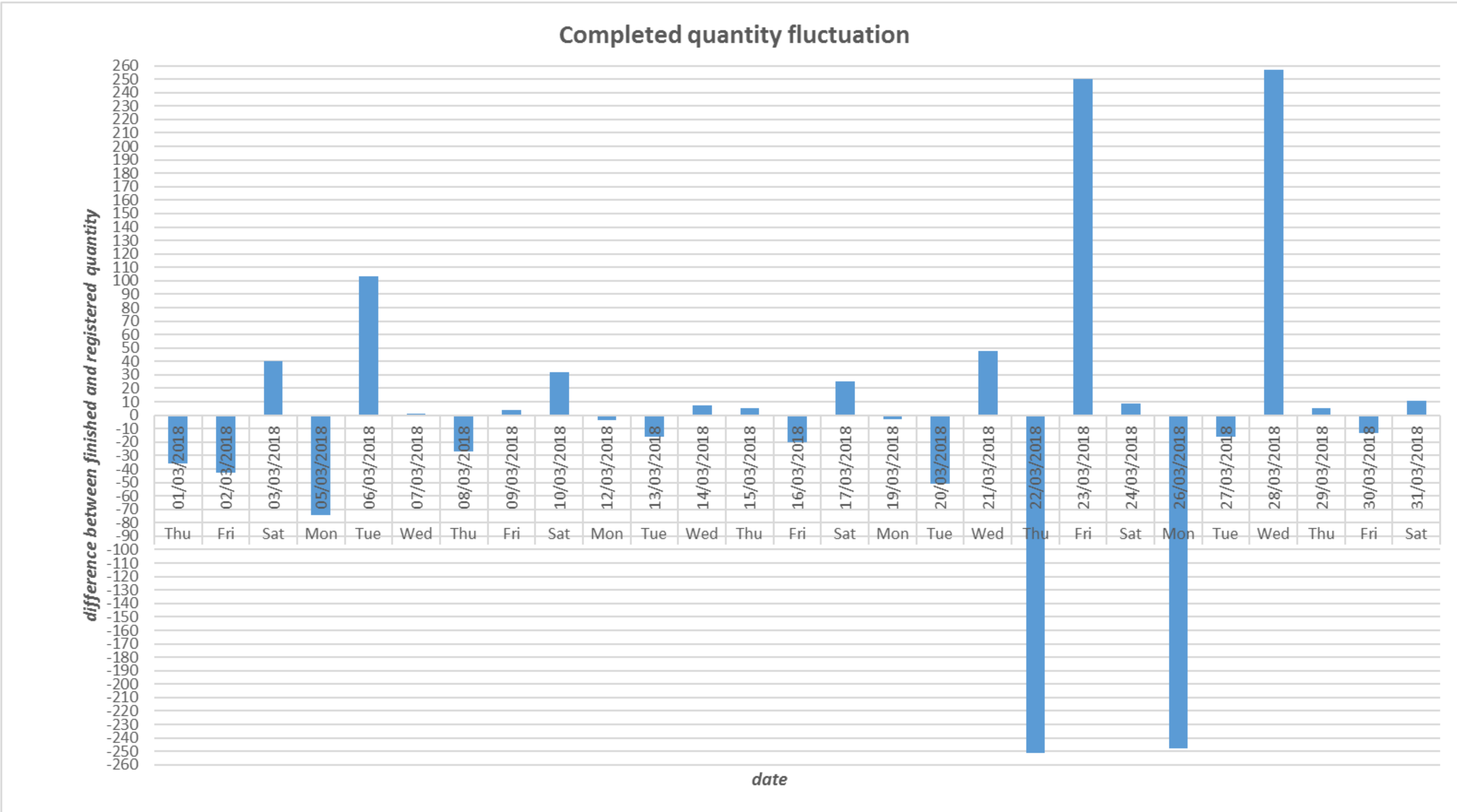

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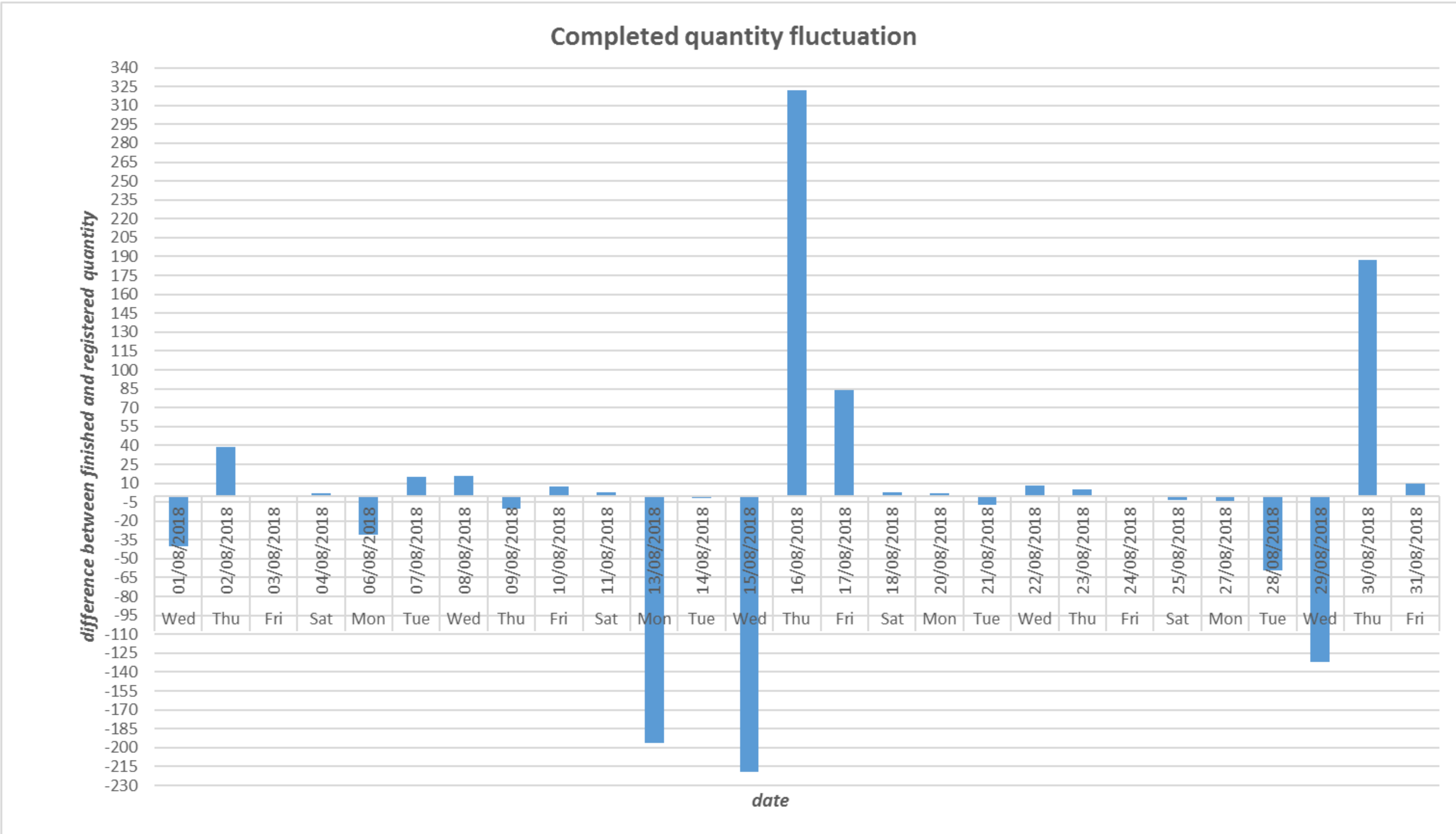
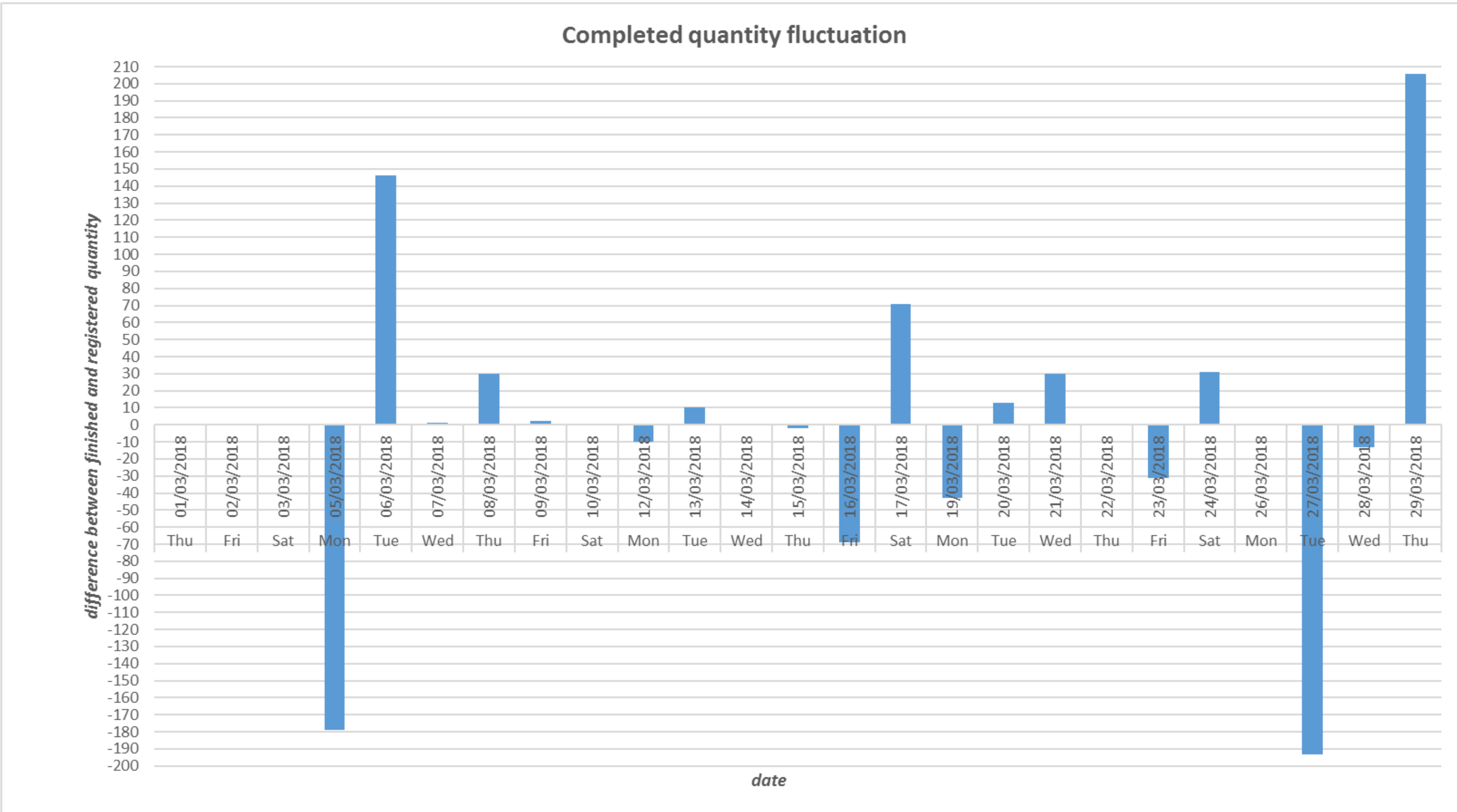
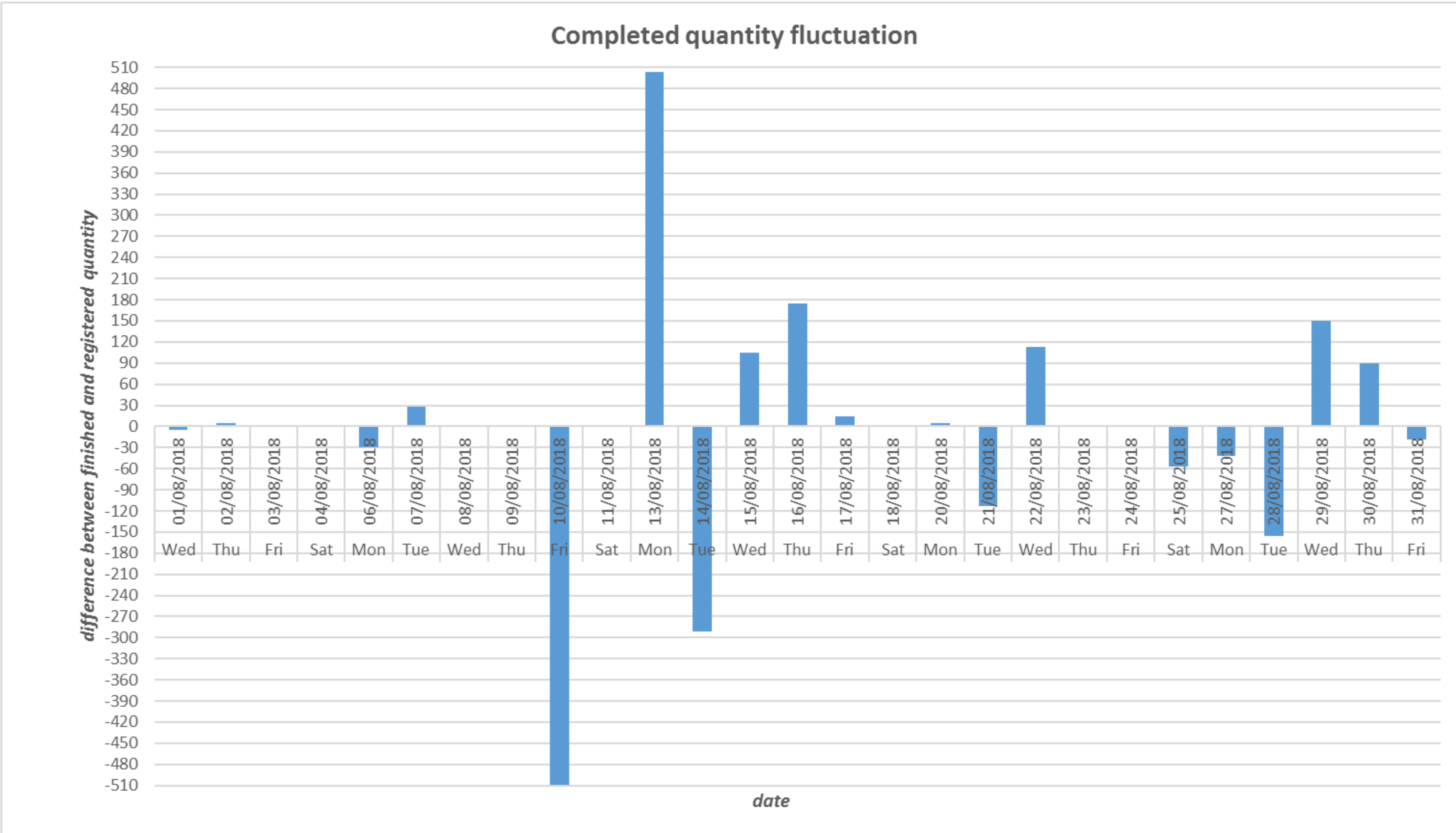


Appendix 23. March not completed Shop replenishment orders quantity fluctuation analysis



Appendix 24. August not completed Shop replenishment orders quantity fluctuation analysis



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