Line Regulation and Accumulation
White paper

Sidel

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1 Introduction

1.1 Background

Zenith Global Ltd. (Zenith) have been engaged on behalf of Sidel to produce a white paper as an independent review of the potential benefits on line efficiency through the use of line regulation and accumulation solutions.

1.2 Scope of the work

The scope work for this desk study was detailed as follows:

- Carry out research into the key focus markets to gain an insight into production line set up in the following industries:
    - Food manufacture.
    - Personal care.
    - Home care.
- Identify supporting evidence around production line design and the effect of line regulations and product accumulation on line performance.
- Identify types of packaging which may benefit from line regulation and accumulation including:
    - Jars.
    - Bottles.
    - Irregular shaped and difficult to transport packaging.
- Produce an independent white paper setting out findings and recommendations for line regulation and accumulation systems.

1.3 Approach

First, we completed research of current and historical design of packaging line theory and analysed the data for suitability for use in this document. We then reviewed the effect on line performance using models of different scenarios to give the reader an understanding of the benefits of accumulation and factors that require consideration. Finally, by using our own knowledge and experience in this field, we have given advice and made recommendations to potential clients considering accumulation in their application.

2 Production line design

2.1 Equipment manufacturers design and considerations

When considering line regulation and accumulation solutions, the client will be guided throughout the process by a suitably experienced machine supplier to ensure that the solution will meet the set acceptance criteria and performance requirements. Each packaging line project is bespoke and Zenith recommend clients to make their requirements clear in a project scope document. The client could have restrictions on their project which could compromise a line regulation and accumulation solution suggested by the machine manufacturer.

Zenith recommend clients contact the 'Process and Packaging Machinery Association' or equivalent when researching the market for a line regulation and accumulation solution.
(http://www.ppma.co.uk)

2.2 Manufacturing overview

In 1984 Hayes and Wheelwright suggested that companies compete in the marketplace by virtue of one or more of the following competitive priorities:

- Quality
- Lead-time
- Cost
- Flexibility

Many would consider that these elements can largely be controlled by the manufacturing department of the organisation and by measuring the overall equipment efficiency or OEE, companies can achieve insight into how well they are performing against internationally recognised standards and benchmarks.

It is therefore imperative that not only a new line is built following set design criteria and fit for purpose, but the performance levels of existing lines are evaluated against the same criteria which must include performance and quality.

There are multiple reasons which can impact a manufacturer to supply products on time, in full, at the right price and at the highest quality.

We will detail throughout this paper that having stoppages for machine related issues will directly impact the line performance and the profitability of an organisation. However, equal consideration should also be given to a stoppage due to a quality related concern such as product contamination, defective materials such as closures or primary and secondary packaging, all of which will result in the line stopping and the line potentially needing to be cleared, causing unnecessary downtime and in the case of product spoilage, additional losses such to the costs of the material affected and cleaning chemicals, effluent are also important considerations.

2.3 Operational efficiency definitions

2.3.1 OEE calculations

OEE (Overall equipment effectiveness) is a term commonly used in industry to quantify production line performance and is calculated using three factors Availability, Performance, and Quality.

Figure 1 OEE calculation

Slide referenced from: https://www.leanproduction.com/oee.html

Availability

Availability takes into account all events that stop planned production for an appreciable length of time, and includes unplanned stoppages such as equipment failures, and planned stoppages such as changeovers.
Availability = Run Time / Planned Production Time
Where Run Time = Planned Production Time − Stop Time

Performance

Performance takes into account **Performance Loss**, which includes all factors that cause the production to operate at less than the maximum possible speed when running, including slow cycles and small stops.
Performance = (Ideal Cycle Time × Total Count) / Run Time
Ideal Cycle Time is the theoretical fastest possible time to manufacture one piece. Therefore, when it is multiplied by Total Count the result is Net Run Time.

Quality

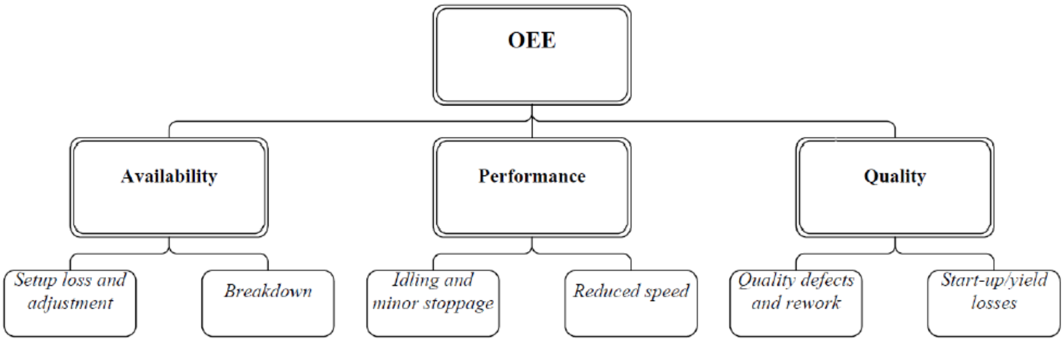
Quality takes into account **Quality Loss**, which factors out manufactured goods that do not meet quality standards, including pieces that are later reworked.
Quality = Good Count / Total Count

Whilst OEE is an important factor in determining the efficiency of a packaging line, it does not consider the cost of replanning products, waste disposal costs, effluent treatment or labour costs as a result of reduced line performance. Within industry an OEE of 60% is considered typical for discrete manufacturers, but indicates there is substantial room for improvement.

2.3.2 OEE losses

Within the three loss factors OEE can be further classified using the diagram in figure 2. (van Leer, D. 2014)

Figure 2 OEE losses



In the packaging industry, it is well known that accumulation is widely used to reduce the idling and minor stoppages expected in a production line. (Parker, 2018)

2.4 Line design principles

When considering implementing a production line solution, it is important for end users to understand that packaging lines are not like static machinery and that a packaging line includes several pieces of equipment that must be suitably designed as a system, control and communication between equipment is critical. (Ho, 1997).

Within this paper the example given below for a generic packaging line will be used throughout. This example is generic and the principles could be applied to any product.
The basic line design will include:

- Depalletiser
- Filler
- Labeller
- Packer
- Palletiser

Each piece of equipment will be designed to operate at different speeds to each other with one machine designed as the *critical machine*. The critical machine can also be referred to as a 'bottle neck' and is the slowest machine on the line where the line performance is determined. (A. Parker 2018) In the example we have chosen the critical machine is the filling machine, and as well as dictating the line output the critical machine is often critical for product quality, the highest levels of hygiene must be maintained as the product can still become contaminated until the primary packaging is sealed.

During the design phase of a production line the designer will decide on which machine will be the bottle neck, this generally will be the primary process, so a filler for a liquid product (examples soda, shampoo, liquid cleaner or a face cream) or the tabulation process in a pharmaceutical application (examples paracetamol or ibuprofen). (Ho, 1997)

2.4.1 Buffer and accumulation strategy

The goal of a buffer strategy is to minimise the influence of the different machines on each other and especially on the critical machine by accumulating or regulating additional supply before the critical machine and creating space after the critical machine. In other words the buffer areas between the machines provide accumulation. (Harte, 1997).

Accumulation is used to keep the critical machine running when either upstream or downstream machines are stopped.

There are two types of accumulation:

- Static accumulation - typically static accumulation tables or crate stores.
- Dynamic accumulation - typically uses dynamic conveyors or driven tables between the machines.

Table 1 comparison of static and dynamic accumulation

Static	Dynamic
• **Batch traceability is not maintained**	• **Space saving solutions available from manufacturers**
• **Smaller size compared to dynamic**	• **Increased size compared to static**
• **First in last out basis, may not be emptied until the end of production**	• **First in first out basis**

For most modern packaging lines where traceability is critical such as in the personal care, food and home care markets, dynamic accumulation would be the preferred type of accumulation in this instance and forms the focus of this paper.

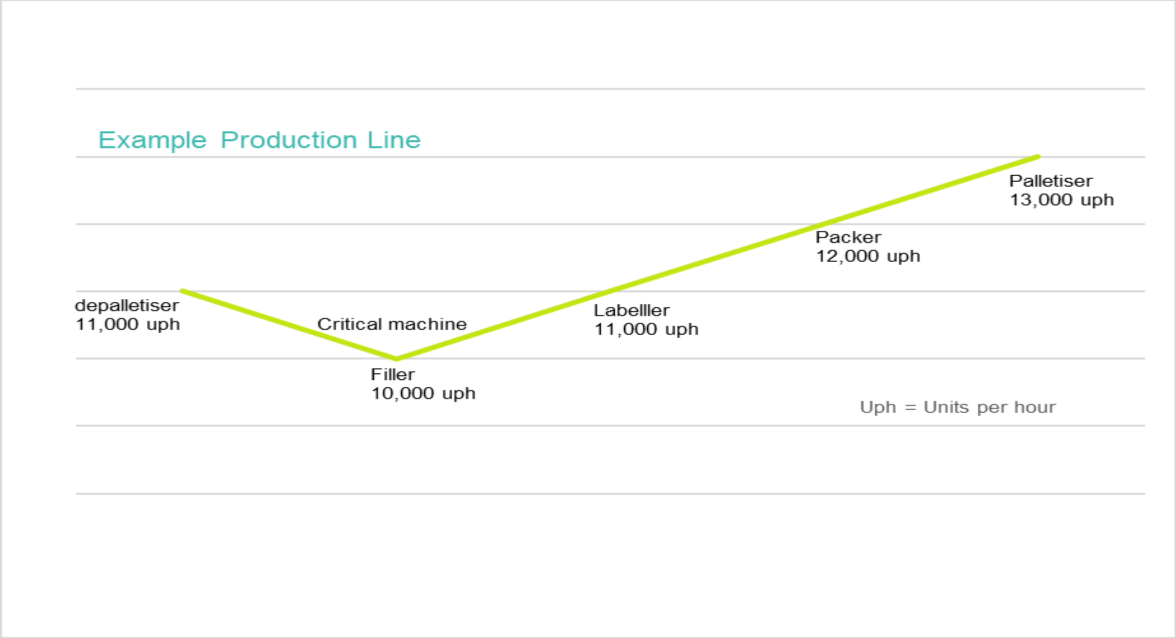
2.4.2 Production line V curve

The speed curve of a line is designed so that the critical machine is at the bottom of the curve with the maximum speed machines before and after the critical machine as described in figure 3.

We can see that the speed of the depalletiser is higher than the speed of the filler, this effective over-speed capability is deliberate and is designed to provide a constant feed to the filling machine, therefore creating a push scenario.

The over-speed capabilities of the downstream equipment is also purposeful and this is designed to create a pull scenario and allows any accumulation that has occurred during a minor stoppage to be used as quickly as possible to free up the accumulation capabilities in case there is another minor stoppage. With machine speeds running at different rates and a constant output being required, then the need for line regulation to control this sequencing should also be considered as a necessity.

Figure 3 production line V curve



Slide referenced from: https://www.slideshare.net/OFXAcademy/line-balance-optimisation

3 Accumulation benefits

3.1 Accumulation models - performance benefits

As previously discussed in section 2, accumulation is a recognised practice used to keep a production line running during small stoppages that reduce line performance. In this section the benefits of accumulation will be examined further by taking two theoretical line designs:

- Production line - without accumulation
- Production line - with accumulation

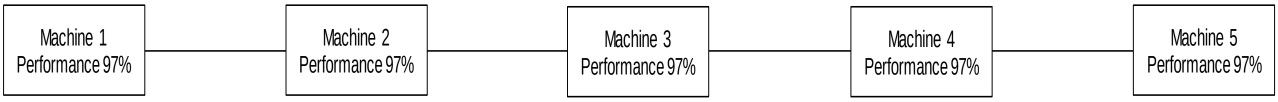
In this section the effect of accumulation on line performance will be identified using two theoretical scenarios.

The calculations to determine line performance are complex and defined in DIN Standards. (DIN 8743) These formulas are complex and Zenith recommend that client seek advice from specialist manufacturers with experience in line design. Zenith also recommend that clients do not underestimate the complexity of the calculations required to determine the correct amount of accumulation in a production line. Again, we suggest that clients work with specialist manufacturers.

Each machine described in the figures below will have its own operational efficiency as defined by the manufacturer and an internationally recognised DIN standard, typically 92-97%. (DIN 8743)

3.1.1 Without accumulation

Figure 4 production line - without accumulation

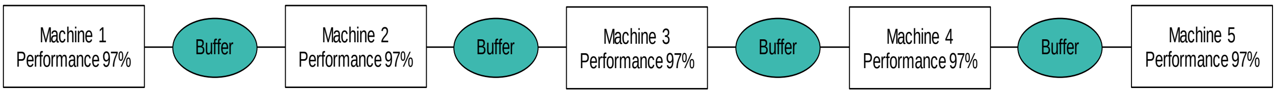


The machine layout on close coupled machines is minimised with no space for accumulation. With this layout the instance that one machine stops results in the whole line stopping in a very short period of time.

The likelihood of all machines stopping simultaneously is negligible. Therefore, to calculate the performance of the complete line, each machine's performance is multiplied by the following machine's performance, resulting in a line performance level of 85.8%. (DIN 8743)

3.1.2 With accumulation

Figure 5 production line - with accumulation



The machine supplier has designed the line with the optimum amount of accumulation and buffer to minimise the impact of minor stoppages on the overall performance of the line. By implementing this methodology, the overall performance level of the line will be maintained at 97%.

3.2 Accumulation models - benefits

The line performance from section 3.1 can be summarised in the following table:

It is clear that a suitable accumulation solution increases line performance, however this does not quantify performance losses.

Interestingly when carrying out our research on financial benefits of accumulation there was limited data available. This is most likely due to clients and equipment suppliers withholding sensitive commercial information and that accumulation principles are known to be beneficial to clients purchasing a production or accumulation solution.

There are in principle two ways of evaluating the loss of performance on a production line: (Symeonides, C. 2007)

- Hourly labour rate
- Extra capacity

For the purposes of this model, Zenith have chosen to use extra capacity to quantify accumulation benefits. Whilst it may be helpful to understand the additional labour cost associated with not using an accumulation system, in reality this is difficult to justify based on the assumption that most manufacturing businesses have fixed shift patterns and therefore costs in their labour calculations. The extra capacity method assumes that there is a market for selling the product at the same margin.

3.2.1 Accumulation models - parameters

Zenith believe that it is important for clients to understand the financial benefits of an accumulation solution and as a result we have developed a model to quantify accumulation benefits.

The model makes a set of assumptions on a theoretical production line with the following parameters, with further analysis for the different line speeds are given in appendix 2:

- 10,000 units per hour production line.
- Production line running time, 24 hours per day, 5 days a week.
- The profit per unit is €1.2.
- Can be adapted and applied to any product in any industry.

Table 3 production line performance - impact of accumulation

	With accumulation	Without accumulation
Performance (%)	**97**	**85.8**
Reduction in units (/hr)	**0**	**1,120**
Lost opportunity (€/hr)	**0**	**1,344**
Lost opportunity(€/annum)	**0**	**7,741,440**

3.2.2 Accumulation models - conclusions

- Higher speed lines without accumulation will see a greater reduction in units produced.
- Reduced need for accumulation for lower speed lines.
- As the number of discrete machines increases and the line becomes more complex, the need for a suitable accumulation system increases.
- The impact on lost opportunity each year is significant and highlights the need for sufficient accumulation.
- A higher margin product increases the need for a suitable accumulation system as the impact on lost profitability per unit is higher than when processing low cost goods.

Notes and assumptions:

- The model can be used for any product, industry or application.
- The model is purely for the product manufacturers to understand the losses associated with not installing a suitable accumulation system, it is not a guide to actual line performance.
- The model calculates the expected reduction in line output, as a result of not having a suitable accumulation solution.
- The model does not give a reduction in profit as such but does give a clear and simple valuation of the importance of accumulation.
- The model should not be used in place of a financial model showing detailed analysis of the cost make up of a product (cost of good sold and margins).
- The model assumes that the cost of goods sold remains constant and that there is a market for the product.

4 Accumulation - considerations and constraints

In this section, we will discuss factors to be considered and potential constraints in the purchase of an accumulation system.

A Zenith case study identifies that when installing a high speed production facility of 50,000 bottles per hour to a standard design versus a close coupled option shows the following:

- Floor space required could be 30% less with the close coupled design.
- CAPEX cost is 10% lower.
- Performance levels are potentially 11% less with the close coupled option.

4.1 Costs benefit study of accumulation

Typically there are three reasons for a business to make capital investments: (Ward, S. 2018)

- To acquire additional capital assets for expansion, create new products, or add value.
- To increase efficiency and reduce costs.
- To replace existing assets that have reached end-of-life.

Irrespective of the client's reason for investment, Zenith recommends that when considering an accumulation solution, a cost benefit study is done on the project.

The analysis should include:

- The purchase price.
- Installation costs.
- Operating costs.
- Maintenance costs.
- Upgrade costs.
- Remaining (residual or salvage) value at the end of ownership or its useful life.
- COGS (cost of goods sold).

4.2 Available space

A physical constraint is a common problem in existing facilities. (Parker, A. 2018) Every situation should be considered on a case by case basis to determine the cost benefits, and by using the models similar to those detailed in figures 4 and 5 the client can identify a high level scenario on the effective ongoing efficiency reduction and potential lost opportunity for the lifecycle of the installation. This can assist in determining the business case for the additional expense which will be incurred by increasing the space available.

In the beer and bottled water industries, where containers are stable, of a similar design and there is very little diversity between the types of products being packaged, accumulation is already widely used. Machine manufacturers generally supply meters of flat bed accumulation conveyors of varying designs between the line machinery, this assists in modulating the line speed and allows for the impact of the individual machines performance of 97% to become insignificant. However, this type of accumulation utilises a lot of space within a manufacturing facility.

Within the food, personal and home care markets it is not uncommon for multiple products to be produced on several different lines, then the option to have expansive lines is not always viable and often line installations are closely coupled as per figure 4. This approach will impact the line performance and profitability of the organisation. The opportunity to maintain the line performance through conventional dynamic accumulation is limited and OEMs are becoming aware of this challenge and are developing innovative solutions.

Below are 3 examples of accumulation with a first in first out (FIFO) principle, the spiral and buffering conveyors remove the space constraint by using the height within a building which in Zenith's experience will need to accommodate access equipment, whilst the Gebo option maintains the product at a user level.

Figure 6 Gebo AQ Flex®

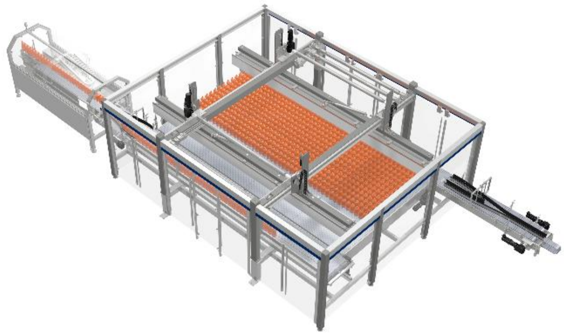


Figure 7 Polyketting accumulation conveyor

Figure 8 Flexlink balancing conveyors

4.3 Line speed

There is little literature or discussion between industry experts on when not to consider accumulation in a packaging line layout because of the well documented benefits. However, apart from having the major constraint of space there are times when the client may not consider including accumulation. Examples from Zenith's experience include:

- Lines that are running at very slow speeds, where the impact of limited accumulation is reduced compared to higher speed lines, as demonstrated in the accumulation model in this report
- Semi-automatic lines where there are manual operations.

4.4 Lean manufacturing and accumulation

The basic principle of lean management is *eliminating waste*. Waste in this context means all activities that add no value to the end product. The principle assumes that eliminating waste will increase the business performance. (Leer, D.V, 2014)

There is a view held that lean processes and accumulation cannot coexist in industry, because of the belief that accumulation is a non-value adding step in the process. However, Knight (2013) believes that accumulation can add value to a manufacturing process. With the critical machine (or bottle neck process of the line) determining the maximum throughput that line can achieve, Knight argues that accumulation adds value by protecting this bottle neck process from the myriad of problems that may be happening on other processes. Zenith's experience of packaging line designs would support the design and installation of suitable accumulation system where feasible.

4.5 Packaging

In the food, personal care and home care industry, product packaging is designed to attract the target markets' attention often differentiating the manufacturer's product from the competition. However, aesthetically pleasing designs do not always consider the practicality of manufacture. Handling of the unfilled containers can often prove difficult as they are unstable and in some cases the neck filling point is off centre. Transporting and filling at higher speeds is much more difficult than uniformly designed containers seen on high speed filling lines. In these instances one solution is the use of puck lines as they provide stability to the container during the production process. Once in the pucks, products can be conveyed and mass accumulated as if they were free standing, stable containers. Unfortunately the products need to be placed in the puck (and later removed) which often slows down the manufacturing process. Irrespective of this constraint, the need to process at the highest performance level is still required.

Many containers however are less complex as they are flat based, stable and easier to handle as shown below but due to the characteristics of the product being filled, i.e. highly viscous or containing solids, they are often filled at much lower speeds of between 8,000 – 15,000 containers per hour.

Whether it is difficult to handle primary packaging or complex product recipes, many manufacturers often revert back to lower speed manual or semi automatic applications and the considerations raised in section 4.3 become the focus of the process.

5 Conclusions and recommendations

5.1 Conclusions

We conclude the following:

- Accumulation and line regulation is already widely used in high speed packaging lines to reduce the impact of small stoppages on line performance and increase the overall performance. However the same benefits are also applicable to lower speed lines often installed in the food, personal care and home care industries.
- Complex formulae are used to design a production line and any associated line control and accumulation system requires specialist knowledge. These elements should be considered as part as the proposal for a new production line.
- Accumulation is used to keep the critical machine supplied with product, upstream machines push product to the critical machine and downstream machines are designed to take product away at higher speeds.
- Complex production lines with multiple machines will see the most benefit of an accumulation system compared with simpler lines.
- Accumulation systems are known to cost more than production lines without accumulation however the reader should consider operating cost and profitability when making a decision on investment for a new line or changes to an existing line.
- Space is a known constraint, especially for existing facilities; however there are space saving options available for accumulation and every case should be evaluated on a case by case basis.

5.2 Recommendations

We recommend the following:

- Use a specialist machine manufacturer with experience in production line design to provide the optimum system for your application.
- Evaluate the capital costs as part of the project justification particularly when considering the implementation of an accumulation system.
- Clients should look to partner with an equipment manufacturer to determine whether their current production line complies with design principles and financially model the potential benefits of future investment.
- If any of the constraints identified in this paper apply to the reader’s decision making process then Zenith would suggest that they involve the potential suppliers and ask about the various options they have in their product portfolio.
- Understand the cost components and margins of the product with a detailed financial model.

ISO 9001:2008 Quality Management System		
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Appendix

Appendix 1 references

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https://www.leanproduction.com/oee.html

Appendix 2 impact of OEE on output at different line speeds

Zenith have made assumptions and calculations regarding profitability set at €1.2 per unit and ran scenarios on 3 different line speeds of 8,000, 10,000 and 12,000 units per hour and then cross referenced this against the three potential line performances.

Scenario with accumulation			Scenario without accumulation running at 85.8%			
Line performance %	97	Potential number of units produced	85.80%	Potential number of units produced	Difference (units)	Lost profit €
Unit cost profit per unit (€)	1.2					
Line speed (units per hour)	8,000					
Bottles produced per hour	1	7,760	1	6,864	896	1,075
Hours available per day	24	186,240	24	164,736	21,504	25,805
Days available per week	5	931,200	5	823,680	107,520	129,024
Weeks available per year	48	44,697,600	48	39,536,640	5,160,960	6,193,152

Scenario with accumulation			Scenario without accumulation running at 85.8%			
Line performance %	97	Potential number of units produced	85.80%	Potential number of units produced	Difference (units)	Lost profit €
Unit cost profit per unit (€)	1.2					
Line speed (units per hour)	10,000					
Bottles produced per hour	1	9,700	1	8,580	1,120	1,344
Hours available per day	24	232,800	24	205,920	26,880	32,256
Days available per week	5	1,164,000	5	1,029,600	134,400	161,280
Weeks available per year	48	55,872,000	48	49,420,800	6,451,200	7,741,440

Scenario with accumulation			Scenario without accumulation running at 85.8%			
Line performance %	97	Potential number of units produced	85.80%	Potential number of units produced	Difference (units)	Lost profit €
Unit cost profit per unit (€)	1.2					
Line speed (units per hour)	12,000					
Bottles produced per hour	1	11,640	1	10,296	1,344	1,613
Hours available per day	24	279,360	24	247,104	32,256	38,707
Days available per week	5	1,396,800	5	1,235,520	161,280	193,536
Weeks available per year	48	67,046,400	48	59,304,960	7,741,440	9,289,728