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Home Inventory Management and Last-Mile Logistics

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***Abstract*—A study of the functioning of last-mile logistics in home inventory management is described. Different patterns of the household consumptions are studied and assumed in the interim. These consumption patterns then form the automatic grocery ordering system leading to what we would refer as a “home inventory management system.” In the futuristic world. This paper focuses on the impact of driverless delivery vehicles and drone delivery to satisfy the demand of the customers in a future scenario where orders are placed automatically by a home inventory management system.**

***Keywords*—driverless delivery vehicle, drones, home inventory management, last-mile logistics**

I. Introduction

In the ever-changing field of logistics, which accounts to 9-14% [1] of the overall cost for industries, it is clear that logistics cost is one of the most vital composites. Logistics can be safely assumed to be extremely valuable in maintaining good customer service levels in the daily groceries industry. Currently, the online grocery sales forms 15% of the overall share of this industry, which is expected to rise to 20% by 2025 [2].

Advancements in computer vision and machine learning technology has enabled the study of grocery consumption of households and the complete automation of this in the near future does not seem very far-fetched. For this paper, this system will be referred to as a “Home Inventory Management System” (HIMS).

A study by McKinsey & Co. predicts that 80% of the deliveries will be made using driverless delivery vehicles (DDVs) in less than a decade given the increase in online grocery sales and the decrease in cost of deliveries using DDVs [3]. A huge potential saving in these costs also lies in delivery using drones, which is currently under its experimental testing phase by online shopping and delivery giants such as Amazon and UPS [4]. Consequently, this paper focuses on the usage of DDVs and drones to manage the logistics network when coupled with a HIMS.

The analysis of the paper has been extensively performed using MS Excel and MATLAB. The future of online grocery shopping is discussed in detail in Section II of this article whereas Sections III–V focus on Methodology, Conclusion and Future Scope of Work, respectively.

II. Background

Grocery Shopping industry has been evolving continuously with the advancement in technology. There has been a tectonic shift from in-store to online-shopping. The biggest challenge faced by the logistics division of this industry is the problem of last mile deliver; the fee the consumers are willing to pay for such deliveries does not suffice the shipping and handling costs incurred by these companies [5]. Consequentially, this paper is a detailed study of the feasibility of the retailers’ ability to manage the spike in online shopping, logistically speaking!

A. Current Scenario

Currently, the online grocery shopping sales in the United States has increased from 6 to 29.7% from 2012 to 2021 as shown in Figure 1.

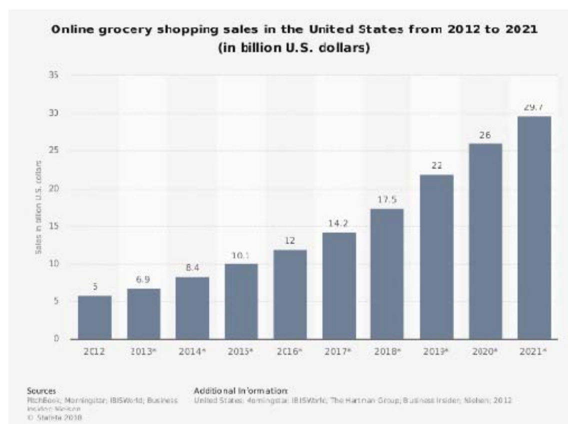

Fig. 1. Online shopping trend in the United States from 2012 to 2021 (in billion U.S. dollars)

Along with the high logistics costs of online shopping, consumers also face a very significant issue related to delivery of their grocery. Like apparels or other appliances that they are currently used to buying online, grocery is perishable when kept in the open and in uncontrolled temperatures. As per the analysis of A.T. Kearney Analysis [5], figures show that 25% of the consumers consider it a hassle to shop online, 10% enjoy in-store shopping, 5% are unaware of shopping for groceries online shopping for groceries and other reasons to not shop for them online contribute to around 16%.

HIMS is clearly still in the inchoate stage and will need new partnerships among companies such as appliance developers, groceries and delivery services.

B. Future: A Projection of a Decade from Now

By 2025 80% grocery deliveries will happen by DDVs and Drones. DDVs are expected to reduce the delivery costs by 50% once they in full operation [5] [6].

Hong et al. [15] propose an Automated Grocery ordering system for smart homes (similar to the HIMS proposed in this article) that can be developed to learn consumption pattern of these smart homes and place the orders automatically. Based on the requirements of these households, daily aggregation happens at the last-mile DC, and routes will be devised each day using a combined drone and DDV delivery to the consumers. This will ensure the economies of the logistics networks at the same time achieving timely delivery of items.

In the model described above the following assumptions are made

1. 100% of the ordering would happen through a Home Inventory Management System.
2. Driverless delivery vehicles and drones would be used for the delivery of the items.
3. All the order aggregation would happen at the last mile DC.

III. METHODOLOGY

A. Household Grocery Demand Estimation in United States

It is necessary to find the number of households in the United States of America to gauge the requirement of the potential number of routes required for the logistics calculations. Information like U.S. population, number of households, weekly demand per household, percentage of internet users, online shopping frequency, online penetration rate, E- commerce sales were derived from different sources like Statistica and US bureau. [7] [8] [9] [10] [11] [12] [13].

Average distance which a household travels for the grocery shopping is 4 miles as per the United States Environmental Protection Agency [14]. This data is useful in identifying the distance that the last mile DC should serve to satisfy 100% demand of online ordering system, the HIMS.

The calculations the average household and online shopping frequency is as presented below. The data is also used from a world-wide study of online shoppers as shown in Figure 2. [11]

1. Average Household Size = U.S. population / Number of households
2. Online Shopping Frequency per Online Shopping User: ((16*52) + (23*26) + (31*12) + (17*16) + (12*4))/ (52+26+12+16+4)/52
   The weighted average of the shopping frequencies is converted as "trips/week/online shopper" as shown in Table I, below.
3. Number of Online Shoppers = (Percentage of Internet Users * Online Penetration Rate * U.S. population)
4. Average Household Size of Online Shoppers = Number of online shoppers/ Number of Households)
5. Weekly Demand per Household = Average household size of online shoppers * Online Shopping frequency per online shopping user
6. Total demand per household = Weekly Demand per Household (In Person) + Weekly Demand per Household (Online)

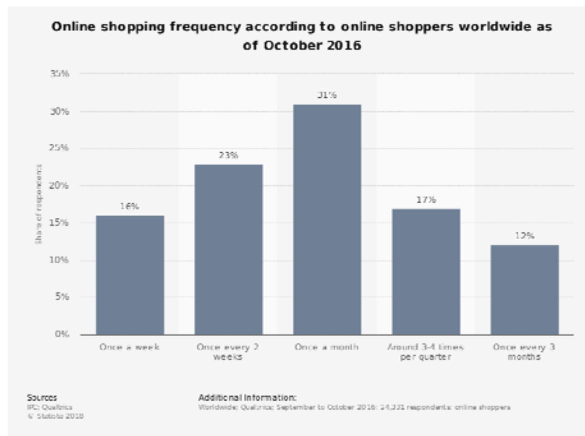

Fig. 2. Online shopping frequency according to online shoppers worldwide as of October 2016

B. Decay rate of perishables

As mentioned earlier, the perishables prove a challenge for the realization of the HIMS system. While delivering the item to the consumer, the retailer cannot have such items sitting at the last mile DC for a very long time depending on the shelf life of the item. The calculation of the life and the deterioration in cost of these items then become one of the key aspects considered while fulfilling a customer demand.

For calculations, let x be the cost of an item. The cost function of the item is given as follows:

$$f(x) = \begin{cases} x, & t \le td \\ xq(t), & t > td \end{cases}$$

Then the quality of deterioration is

$$q(t) = q_0 e^{-k_0 t_i}$$

where

$q_0 =$ intial quality of item

$k_0 =$ decay rate

$t =$ time of delivery

$td =$ due date

The decay rate k_0 for each of these items can be retrieved from the grocery stores themselves. This rate is a vital component of every such business. Once we have this data, the calculation of value deterioration in terms of cost is an easy calculation.

TABLE I. HOUSEHOLD GROCERY TRIPS/WEEK ESTIMATION

Parameter	Value	Unit
U.S. population	325,719,178	people
Number of households	135,697,926	house
Average household size	2.4	people/house
Weekly demand per household (in person)	1.5	trips/week/house
Percentage of Internet Users	87.90%	of population
Online Shopping Frequency per Online Shopping User	0.370979021	trips/week/online shopper
Online penetration rate (US 2017)	77%	of population
E-Commerce Sales/quarter	11136900000	dollars
Number of online shoppers	220456511.2	people
Average household size of online shoppers	1.624612238	online shoppers/house
Weekly demand per household (online shopping)	0.6	trips/week/house
Total demand per household (online + in person)	2.1	Trips/week/house
Average Miles travelled by US house hold for shopping	4	miles

C. *Demand Simulation & Aggregation*

Four scenarios are used for the simulation of grocery demand aggregation. One is a Bachelor working at Lenovo in RTP, another is a household of a couple who have three children one of who is an adolescent, a child and another infant, the third scenario is that of a couple who have an infant baby and a dog, and the final scenario is a house with four vegetarian students living together who are currently pursuing their Master's in industrial engineering at NC State University. These scenarios have been assumed such that they represent a wide range of the types of households in the US, and how their demand will vary. It is carried out for thirteen different products. The average demand for these items is assumed to be the national average and a standard deviation for each scenario is assumed approximately.

For example, the analysis carried out on the first house with a Single Bachelor is presented below. A normal distribution gives the normal demand per item per household mentioned in Table II.

This normal demand is then simulated for 52 weeks (one year) and the average of these 52 weeks is the studied weekly demand for an item presented in Table III.

Then, 6th of May will be day zero, when the first order will be placed by all these houses, the first day of the start of this system cycle. The amount ordered by each household will depend on the decay rate of the item as calculated in Section III-A, the space available in each of these houses to store the items and finally the choice made by the individuals. Table IV below represents the weekly ordering cycle by the bachelor.

TABLE II. NORMAL DISTRIBUTION OF GROCERY DEMAND OF A BACHELOR

Item	Mean Quantity	Std Dev	Normal	Unit
Onion	2	0.5	2.5	Pounds/week
Apple	1.6	0.4	2	Pounds/week
Chicken	1.2	0.7	1.8	Pounds/week
Sugar	2.5	0.6	3.1	Pounds/week
Corn Flour	0.6	0.6	1.2	Pounds/week
Potato	0.9	0.7	1.7	Pounds/week
Toilet Paper	0.5	0.8	1.3	Rolls/week
Pizza	0.4	0.2	0.6	Pounds/week
Diapers	0	0	0	Numbers/week
Pet Food	0	0	0	Pounds/week
Bar Soap	0.5	0.7	1.2	Pounds/week
Candies	132.44	0.6	133	Pounds/week
Toothpaste	1.8	0.9	2.6	Pounds/week

TABLE III. AVERAGE WEEKLY DEMAND OF GROCERIES FOR A BACHELOR

Item	Avg weekly demand
Onion	2.391510466
Apple	2.053839796
Chicken	1.746683998
Sugar	2.992448871
Corn Flour	1.151706229
Potato	1.365888944
Toilet Paper	1.135318322
Pizza	0.873657566
Diapers	0
Pet Supply	0
Bar Soap	0.905086394
Candies	133.6083577
Toothpaste	2.262786014

TABLE IV. GROCERY ORDER CYCLE OF THE BACHELOR

Average of the 52 weeks		Ordered			
Item	Avg weekly demand	6-May	Duration next order (days)	9th May	12th May
Onion	2.4	2.5	8	0	2.5
Apple	2.1	2.5	9	0	2.5
Chicken	1.8	1	5	1	0
Sugar	3	12	29	0	0
Corn Flour	1.1	6	37	0	0
Potato	1.3	2	11	0	0
Toilet Paper	1.1	12	74	0	0
Pizza	0.8	0.3	3	0.3	0.3
Diapers	0	0	0	0	0
Pet Supply	0	0	0	0	0
Bar Soap	0.9	20	155	0	0
Candies	133.6	100	6	0	0
Toothpaste	2.3	20	62	0	0

D. *Analysis*

A very important study of the next day a delivery needs to be made to this house. The average demand for onion is 2.39 lbs., and on 6th of May an order is placed for 2.5 lbs. of this item. By calculation, this amount should suffice for the next seven days and the next delivery for onions can be made on the

8th day. On inspecting all the items on the list, it is evident that Pizza is ordered every three days. Therefore, the order for pizza will be the “trigger order” [16] for the system. Since the amount of chicken also is exhausted in 5 days, the trigger order on 9th May will also include the delivery of 1 kg chicken. The calculation is carried further in the similar manner.

After simulating the same demand variation for all the four houses (see Appendix), we arrive at the aggregated demand for all of them which can be added to aggregate the delivery a DC has to make each day (for the days calculated above) in Table V. This table also represents the number of trips that the DDV must make each day in order to satisfy the weekly demands of the houses it serves.

TABLE V. AGGREGATED GROCERY DEMANDS FOR A WEEK OF 4 HOUSEHOLDS; NUMBER OF DDV TRIPS/WEEK

	Order Quantity in Pounds				***Order***	**# of**
Date	Bachelor	Household	Couple	Students	***Sum (lb)***	**Trips**
6-May	178.3	675.3	8374.5	591	9819.1	12
7-May				4	4	1
8-May		2.3		8	10.3	1
9-May	1.3				1.3	1
10-May		0.3	7		7.3	1
11-May					0	0
12-May	5.3				5.3	1
13-May			9.3		9.3	1

E. Locating the Last-Mile DC

This study constrains the area within Raleigh, Durham, Cary and Chapel-Hill. The last mile DCs can be located based on the population aggregation. Based on the population aggregation run by a MATLAB code using the FIPS data, Delaunay Triangulation and Convex Hull techniques, the following aggregate demand points are observed in Figure 3.

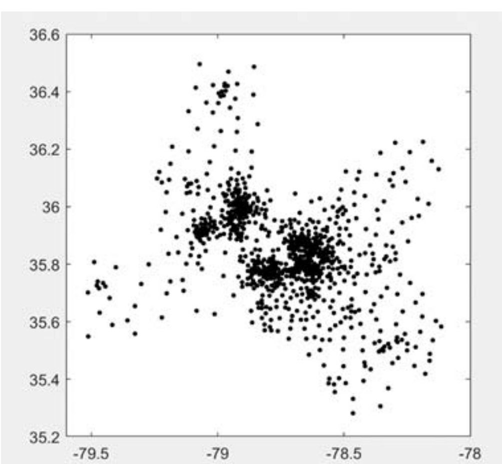

Fig. 3. Population demand aggregated last-mile DCs

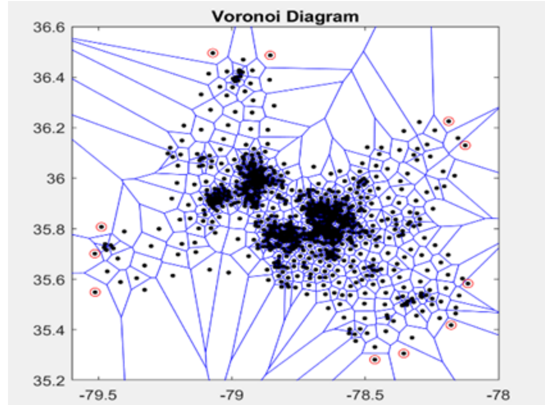

Fig. 4. Voronoi diagram of the area served by each DC

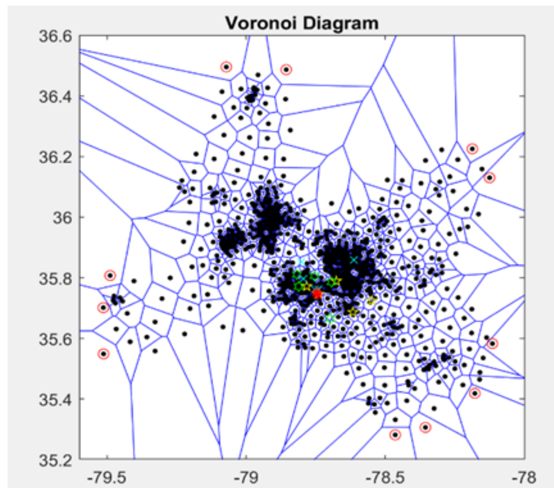

Fig. 5. Grocery & other stores plotted as per Table I

As seen in the diagram, the coordinates (–79.6 35.2) to (–78 36.6) represent the area/region which the study is constrained to, as mentioned above. The black dots represent the last mile DCs. Because these DCs have been located based on population aggregation, it becomes clear why some areas have DCs located very close by (densely populated regions) and others have them scattered far apart.

Once these DCs are located, it is also intriguing how much area they can serve to. For this study, the area served by each DC is also calculated based on the population that it will serve too. This calculation and representation is also carried out on the Figure 3 map using a Voronoi diagram and Convex-Hull technique. In Figure 4, the blue line is the boundary representation of the area served by each DC. This represents the densely populated downtown and near-by areas of the four cities in the analysis and the spread-out outskirts of the city.

After locating these DCs, the Walmarts, CVS Pharmas, Dominos stores, Dick Sporting goods shops have been located at various locations. The location of these stores is as shown in Figure 5. Further, four houses served by a single last mile DC are chosen at random. These are then located at their coordinates (–78.745, 35.749), (–78.7444321, 35.742111), (–78.74121, 35.744441), (–78.745, 35.754)

To perform the routing on these houses, the demand aggregation simulation carried out in Section III-B will be made use of which also determines the number of trips required to be made per day by DDVs from the local DCs to the houses.

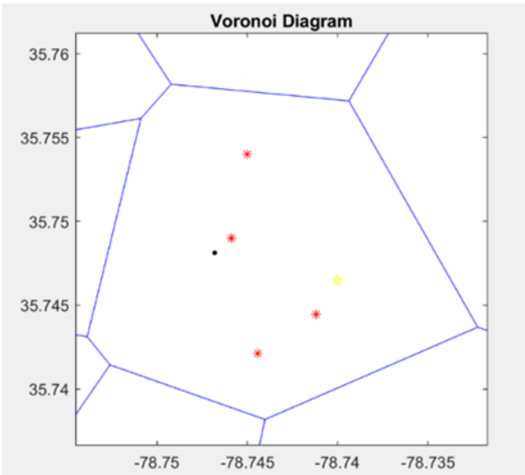

Fig. 6. Plot of the four households

IV. CONCLUSION

Establishing the importance of logistics and the costs associated with it plays a vital role in the design and analysis of a Home Inventory Management Systema. With an increase in the percentage of online shoppers, there is a need for improving the current systems in place along with the design of a new system that will be more robust and accommodating, at the same time be a state-of-the-art technology. With a few inherent assumptions, a Home Inventory Management System is proposed, and its analysis and results have been explained in this paper.

As seen in Section III-A, the average number of orders per household is 2.1 trips per week/household; and the total number of households in the US is approximately 135 million. This information would be of a great asset when expanding the Raleigh-Durham region analogy to the continental United States sector.

The decay rate factor concluded in Section III-B can be used to identify potential losses in the profits of the retailers upon delays in the deliveries or for other slacks observed in the supply chain.

For the households considered in the paper, it is observed in Section III-C that on average around one route is required for the delivery per day. The results of section III-C can be further combined with the results of Section III-A, to extend the analogy for the entire U.S.

Section III-D emphasizes on the location of the last mile DCs based on the population aggregation. The last mile DC would approximately be covering 4-mile distance for the economic feasibility of the logistics network which forms the future scope of the project. For our model, a total of 858 last mile DCs have been located using Vornoi, Convex Hull, Delaney Triangulation techniques.

By making improvements over time as discussed in the future scope, the results of Section III can be used to cover the entire US sector to manage a 100% HIMS.

V. FUTURE SCOPE

Since this article proposes a new model for last-mile delivery, it presents a large scope for future work. Since the foundation of the model has been set on the forecasted data, it is necessary to give feedback to the model and bring continuous improvements so that the output of the model adapts continuously and gives accurate results. The constraints of the delivery time window and weight capacity of the DDV can be added to further the accuracy in the number of routes required in a day.

Once the above constraints are incorporated into the model, the scope of the project can be expanded to the entire U.S. Economic advantages of the model presented in the paper can be compared with the existing models to realize direct monetary benefits. The restrictions imposed by the government on the usage of drones and driverless delivery vehicles upon commercialization needs be accounted for every time there is a change in the policy. A detailed study of the class of items that can be delivered through drone and those which can be delivered through a driverless delivery vehicle can be done to achieve best economic feasibility.

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APPENDIX

TABLE VI. NORMAL DISTRIBUTION OF GROCERY DEMAND OF A FAMILY OF FIVE

Item	Mean Quantity	Std Dev	Normal	Unit
Onion	5	0.94	5.92	Pounds/week
Apple	7	0.54	7.53	Pounds/week
Chicken	6.02	0.29	6.3	Pounds/week
Sugar	12.40	0.32	12.71	Pounds/week
Corn Flour	3.27	0.40	3.66	Pounds/week
Potato	4.64	0.78	5.41	Pounds/week
Toilet Paper	2.69	0.77	3.44	rolls/week
Pizza	1.55	0.36	1.9	Pounds/week
Diapers	7	0.48	7.47	packs/week
Pet Food	0	0	0	Pounds/week
Bar Soap	2.41	0.72	3.11	Pounds/week
Candies	662.2	1.23	663.41	Pounds/week
Toothpaste	8.8	0.75	9.54	Pounds/week

TABLE VII. GROCERY ORDER CYCLE OF FAMILY OF FIVE

Average of the 52 weeks		Ordered			
Item	Avg weekly demand	6-May	Duration next order (days)	8-May	10-May
Onion	5.53	6	8	0	0
Apple	7.53	9	8	0	0
Chicken	6.47	2	3	2	0
Sugar	12.86	25	14	0	0
Corn Flour	3.85	25	46	0	0
Potato	5.18	3	5	0	0
Toilet Paper	3.15	30	67	0	0
Pizza	2.01	0.3	2	0.3	0.3
Diapers	8.01	15	14	0	0
Pet Supply	0	0	0	0	0
Bar Soap	2.94	20	48	0	0
Candies	663.3	500	6	0	0
Toothpaste	9.22	40	31	0	0

TABLE VIII. NORMAL DISTRIBUTION OF GROCERY DEMAND OF A FAMILY WITH A PET

Item	Mean Quantity	Std Dev	Normal	Unit
Onion	4	0.48	4.47	Pounds/week
Apple	3.2	0.09	3.29	Pounds/week
Chicken	2.40	0.12	2.53	Pounds/week
Sugar	4.96	0.53	5.48	Pounds/week
Corn Flour	1.31	0.51	1.80	Pounds/week
Potato	1.86	0.46	2.31	Pounds/week
Toilet Paper	1.08	0.16	1.24	rolls/week
Pizza	0.26	0.01	0.26	Pounds/week
Diapers	7	1.69	8.66	packs/week
Pet Food	6160	456.8	6607.6	Pounds/week
Bar Soap	0.96	0.11	1.07	Pounds/week
Candies	264.8	1.93	266.7	Pounds/week
Toothpaste	3.52	0.92	4.424454657	Pounds/week

TABLE IX. GROCERY ORDER CYCLE OF FAMILY WITH A PET

Item	Avg weekly demand	6-May	Duration for next order (days)	10-May	13-May
Onion	4.48	5	8	0	5
Apple	3.62	4	8	0	4
Chicken	2.88	2	5	2	0
Sugar	5.42	15	20	0	0
Corn Flour	1.75	10	40	0	0
Potato	2.31	3	10	0	0
Toilet Paper	1.52	20	92	0	0
Pizza	0.35	0.5	11	0	0.3
Diapers	7.95	5	5	5	0
Pet Supply	6641.25	8000	9	0	0
Bar Soap	1.43	20	99	0	0
Candies	266.11	250	7	0	0
Toothpaste	4.05	40	70	0	0

TABLE X. NORMAL DISTRIBUTION OF GROCERY DEMAND OF STUDENTS

Item	Mean Quantity	Std Dev	Normal	Unit
Onion	6	0.17	6.17	Pounds/week
Apple	9.6	0.95	10.53	Pounds/week
Chicken	0	0	0	Pounds/week
Sugar	9.92	0.85	10.76	Pounds/week
Corn Flour	1.31	0.42	1.72	Pounds/week
Potato	5.57	0.88	6.44	Pounds/week
Toilet Paper	2.69	0.79	3.47	rolls/week
Pizza	3.54	0.25	3.78	Pounds/week
Diapers	0	0	0	packs/week
Pet Food	0	0	0	Pounds/week
Bar Soap	1.92	0.39	2.31	Pounds/week