

RESEARCH ARTICLE

# Evaluation of automated in-line precision dairy farming technology implementation in three dairy farms in Italy

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**Abstract** In recent decades, dairy farms have been exposed to wide variation in profit levels due to a considerable variability of milk price, and energy and feed costs. Consequently, it is necessary for the dairy industry to improve efficiency and productivity by adopting innovative technologies. The automated in-parlour milk analysis and separation is mainly useful to produce low or high quality milk and to monitor the animal health status. Milk with high levels of protein and fat contents may reduce the intensity of standardization during cheesemaking process, reducing production costs. The study aimed to evaluate the efficiency of real-time milk separation during milking and the performance of the milking machine after implementation of AfiMilk MCS. In addition, the economic aspects were assessed. The separation of milk required the existing milking parlors to be equipped with an additional milking line to allow channeling milk with low and high coagulation properties into two different cooling tanks. The results showed that the high coagulation milk fraction, compared to the bulk milk, increased in fat (from 18% to 43%) and protein (from 3% to 7%) concentration. The technology tested has given promising results showing reliability and efficiency in milk separation in real time with affordable implementation costs.

**Keywords** cheese yield, infrared analysis, milk quality, real-time measurement, sensor

## 1 Introduction

In recent decades, the dairy industry manages production according to high quantitative and qualitative criteria, placing modern dairy farming within a highly competitive national and international supply chain. However, dairy farms have been exposed to wide variation in profit levels

due to considerable variability of milk price, and energy and feed costs<sup>[1–4]</sup>. For these reasons, it is necessary that the dairy industry improves competitiveness by adopting innovative production processes and improving animal welfare. Improvement and miniaturization of sensors along with continuing costs reduction encourage the implementation of new technologies in dairy farms, allowing increases in their efficiency and productiveness<sup>[5–7]</sup>.

In these terms, the use of a milk analysis system in real time for each individual cow will be a useful way to monitor modern dairy farms<sup>[8]</sup>. This is part of the management system known as Precision Livestock Farming (PLF), which aims to do the right thing at the right time<sup>[9]</sup> and outlines a new approach to the application of advanced technologies in the livestock sector<sup>[10]</sup>.

Milk composition varies from animal to animal depending on the production stage and many other factors (such as nutrition, physiologic status and health)<sup>[11,12]</sup>. For this reason, different animals and breeds have been selected and diverse dairy products have been refined according to standard requirements<sup>[13–15]</sup>.

The automatic assessment of milk composition is useful for several reasons: (1) to differentiate animals producing low- or high-quality milk<sup>[16]</sup>, (2) to monitor animal health status<sup>[17–19]</sup>, and (3) to perform a real-time separation. In particular, the separation of milk may be a useful way to obtain two products with different quality characteristics, such as nutraceutical cheese-making properties, from the same dairy farm.

Separation of milk during milking procedures is an innovative way to improve the value of milk. AfiMilk MCS is a technology that can be implemented in milking parlors, and allows two different fractions of milk to be obtained based on a near-infrared spectrum light scattering (which does not manipulate, modify, heat or add any ingredients to the milk)<sup>[20–22]</sup>. By channeling the milk into two fractions, according to predetermined qualitative characteristics (e.g., fats, proteins and coagulation properties), the cheese yields can be increased. Thus, cheese-making plants have the advantage of withdrawing milk

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with specific characteristics closest to those required by the target recipe for cheese production or whole milk for drinking.

In addition, diversification of production also requires a revision of the logistics of the milk collection, which is of considerable importance in the collection and delivery of milk<sup>[23,24]</sup>.

The adoption of PLF technologies can minimize the environmental impact of farms, increase their economic sustainability and improve livestock welfare<sup>[25–27]</sup>. The energy requirements and environmental sustainability of the new method of separation and collection of milk have been calculated through a life cycle assessment approach, and found to provide important energy and environmental benefits along the entire milk supply chain<sup>[23]</sup>.

In this context, the objectives of this study were: (1) to evaluate the milk channeling efficiency of an innovative technology, implemented in milking parlors, for the real-time analysis and separation of milk with different compositions, (2) to evaluate the working performance in these milking parlors, and (3) to estimate the implementation costs of the AfiMilk MCS systems on dairy farms.

## 2 Materials and methods

### 2.1 Dairy farms characteristics

This study was conducted on three commercial dairy farms located in Oristano Province, Sardinia, Italy. The farms specialized in milk production with confinement management and were located in a valley. The specific characteristics of the three dairy farms were: Farm A, land area of 72 ha, 500 head of Italian Holstein (90%) and Brown Swiss (10%) cows, monthly milk production 178400 kg, 8 + 8 herringbone milking parlor equipped with low-level milkline; Farm B, cropped land area of 85 ha, 600 heads of Holstein cows, monthly milk production of 204000 kg, herringbone milking parlor 15 + 15 stalls with low-level milkline; Farm C, land area of 100 ha, 480 heads of Holstein cows, 193100 kg of milk production per month, 9 + 9 stalls in a herringbone milking parlor with low-level milkline.

### 2.2 Real time milk separation

During milking, the milk separation took place in real time for individual cows. This was made possible by the installation of an AfiMilk MCS system (online milk classification service; AfiMilk Ltd., Afikim, Israel) on each farm. The harvested milk is classified in real time during milking and diverted into two different cooling tanks depending on its coagulation properties. One tank received milk suitable for the production of cheese (CF) and the other drinking milk (DF). AfiMilk MCS is basically

composed of the AfiLab (an optical in-line milk component analyzer) and an electronic lactometer (AfiMilk MPC). AfiLab is installed between the AfiMilk MPC and the milking point, and measures in real time for every lactometer release the composition of the milk each cow gives. This system activates a valve during milking that diverts and channels the harvested milk into different tanks based on its coagulation properties and other related quality criteria (Fig. 1).

In this study, the AfiMilk MCS was set to separate milk with three different series of separation CF:DF ratios: 40:60, 50:50 and 70:30. From each separation ratio, milk samples were collected from the bulk milk tank and transferred within 1 h at 4°C to the ARAS (Associazione Regionale Allevatori Sardegna) laboratory<sup>[28]</sup> in Oristano.

Milk classification was optimized through tests performed in the 15 days before the start of the experiments. For each series of separation ratios, the mean values of bulk milk components were recorded.

The milk parameter considered to evaluate the milk separation efficiency were: protein (%), fat (%), casein (%), casein/protein ratio (%), using Fourier transform infrared spectroscopy (MilkoScan-Foss-Electric, Denmark); Somatic Cell Count (SCC; cell·mL<sup>-1</sup>) using



**Fig. 1** The AfiLab (2) installed next to the AfiMilk milk meter (1) performs real-time analysis of milk components using spectroscopy in the near infrared. Milk with predefined coagulation properties is separated and channeled using specific valves (3) through two different milklines (4 or 5) in a predetermined refrigeration tank.

an automated flow cytometer (Fossomatic FC-Foss Electric, Denmark); Total Bacterial Count (TBC, colony forming units  $\text{CFU} \cdot \text{mL}^{-1}$ ) and amount of milk (kg).

The tests were performed between May and September 2015. The total number of analyses accomplished for each CF:DF were 17 (40:60), 158 (50:50) and 27 (70:30).

Moreover, frequencies, means and standard deviations were calculated for each experiment to characterize the differences between the CF and DF in each separation ratio. Statistical differences ( $P < 0.01$ ) between the two milk fractions were assessed using the Mann–Whitney test (SPSS Inc., Chicago, IL, USA).

### 2.3 Milking machine performance

The separation of milk in real time with the AfiLab MCS system required the installation of a milk meter, an optical reader and two valves to direct the milk in two different lines. To assess the stability of the operative vacuum pressure during milking, specific mechanical field tests were performed for each milking machine. These tests allowed for several measurements and controls, both with animals in milking (milking-time tests) and with the machine running, but no milking (dry tests). The milking-time and the dry tests were performed specifically to measure the mean vacuum and vacuum fluctuations in the milkline, in order to evaluate the changes in the configurations of milking parlors.

Experimental data were recorded with an electronic data acquisition system (DAS-M, Star Ecotronics, Milan, Italy) connected to a portable computer. This system was equipped with four channels with a sampling frequency of 1000 Hz per channel. Pressure sensors operated in the range  $-100$  to  $+150$  kPa with an accuracy of  $\pm 0.25$  kPa at a vacuum pressure of 50 kPa. Data were acquired in real time and recorded in graphical form with two active pointers making it possible to reconstruct a detailed vacuum trend.

During the dry test, the vacuum fluctuations were recorded while two clusters were progressively opened. Vacuum fluctuations were measured at the same time in both milklines connecting the sensors near the receiver. The vacuum level was recorded for a duration of 120–140 s to obtain a mean fluctuation value for different situations.

### 2.4 Implementation costs

The economic analysis was addressed for each dairy farm, taking into consideration all the modifications done for the implementation of the AfiMilk MCS system. The engineering and wiring costs were provided directly by the installer, while the farm manager provided the costs related to any structural work required for the implementation of the additional components in the milking parlor.

## 3 Results and discussion

### 3.1 Milk separation tests

The first assessment performed was the amount of milk separated (Table 1). The results showed an acceptable degree of separation for the two milk fractions in all three dairy farms involved.

The system has shown the ability to separate the milk in real time in accordance with the threshold set. Therefore, the separation is not affected by the cutoff level, i.e., when the separation level is strongly unbalanced (e.g., 70:30).

Fat, protein and casein concentrations between CF and DF were always significantly different across farms and separation ratios.

For all farms, the values of fat and protein in CF were higher with a separation ratio of 40:60 (CF:DF). In particular, fat concentration ranged from 2.06% to 2.53%, while the variation in protein concentration was less (0.23%–0.36%). Compared to bulk milk (CF + DF), each farm showed an increase in the concentrations of fat and protein (Table 2).

On Farm A, the fat and protein concentrations in CF ranged from 18% to 43%, and 3% to 5%, respectively. Farm B showed an increase, compared to the bulk milk, from 23% to 35% for the fat and an increase in proteins ranging from 4% to 7%, while for Farm C the respective ranges were 20% to 38%, and from 3% to 7%. The system can separate CF with different properties, enabling the cheese making process to yields up to 10%–15%<sup>[20–22,29]</sup>.

On all farms, the highest casein concentrations were always found in CF. Compared to bulk milk, the greatest concentration was 7% with the 40:60 ratio. Whereas, the lowest was 2%–3% with the 70:30 ratio. The casein/protein ratio showed no differences across the three ratios of separation. In the same way, small increases (0.1%–0.6%) were found between CF milk with the bulk milk. Total microbial counts were not significantly different between CF and DF. For all separation ratios, the somatic cell count was higher in CF, particularly in the 40:60 ratio. The statistical analysis performed on SCC showed significant differences between CF and DF only in the 50:50 ratio. Although these values were higher in CF milk, the levels obtained in these tests were found to be well below the limit of  $400000 \text{ cell} \cdot \text{mL}^{-1}$ <sup>[30]</sup> and did not compromise milk quality. Monitoring the SCC levels in real time for each individual cow, strongly improved the animal welfare of the herd. In turn, this produced an increase in the milk quality produced. Lombardo et al.<sup>[31]</sup> also evaluated agrochemicals and other environmental contaminants (Ca,  $\text{CO}_2$ ,  $\text{NO}_3$ ,  $\text{NH}_4$ , etc.) in milk, using a selection of specific sensors implemented in the AfiMilk MCS.

**Table 1** Milk component analysis (mean±SD) of the cheese milk (CF) and drinking milk (DF) fractions after the installation of the AfiMilk MCS system in Farms A, B and C

Analysis (n)	CF*					DF*										
	Milk yield/ Total milk (× 10 <sup>3</sup> kg) yield/%	Fat/%	Protein/%	Casein/%	Total bacterial count/(×10 <sup>3</sup> CFU·mL <sup>-1</sup> )	Somatic cell counts/(×10 <sup>3</sup> cell)	Milk yield (×10 <sup>3</sup> kg) yield/%	Total milk yield/%	Fat/%	Protein/%	Casein/%	Total bacterial count/(×10 <sup>3</sup> CFU·mL <sup>-1</sup> )	Somatic cell count/(×10 <sup>3</sup> cell)			
<b>Farm A</b>																
7	2.1±0.27	37±4	5.36 <sup>a</sup> ±0.18	3.34 <sup>a</sup> ±0.06	2.61 <sup>a</sup> ±0.03	78.3±0.3	10±40	213±38	3.7±0.55	63±4	2.83 <sup>b</sup> ±0.14	3.09 <sup>b</sup> ±0.05	2.41 <sup>b</sup> ±0.02	77.9±0.6	13±70	171±24
72	3.1±0.22	50±2	5.00 <sup>a</sup> ±0.12	3.28 <sup>a</sup> ±0.07	2.55 <sup>a</sup> ±0.06	77.8±0.5	13±30	206 <sup>a</sup> ±36	3.1±0.19	50±2	2.50 <sup>b</sup> ±0.11	3.05 <sup>b</sup> ±0.06	2.37 <sup>b</sup> ±0.05	77.5±0.5	13±22	167 <sup>b</sup> ±42
17	4.8±0.92	71±1	4.39 <sup>a</sup> ±0.06	3.17 <sup>a</sup> ±0.02	2.49 <sup>a</sup> ±0.02	78.5±0.5	5 <sup>a</sup> ±10	172±21	2.0±0.11	29±1	2.11 <sup>b</sup> ±0.06	2.91 <sup>b</sup> ±0.02	2.28 <sup>b</sup> ±0.02	78.3±0.6	8 <sup>b</sup> ±20	160±35
<b>Farm B</b>																
6	2.5±0.14	39±3	4.87 <sup>a</sup> ±0.30	3.35 <sup>a</sup> ±0.06	2.61 <sup>a</sup> ±0.06	77.8±0.6	17±80	358±95	3.9±0.25	61±3	2.75 <sup>b</sup> ±0.33	3.04 <sup>b</sup> ±0.03	2.34 <sup>b</sup> ±0.03	77.1±0.6	19±15	275±76
24	3.3±0.24	51±3	4.78 <sup>a</sup> ±0.12	3.35 <sup>a</sup> ±0.03	2.61 <sup>a</sup> ±0.02	77.9±0.5	17±11	305 <sup>a</sup> ±45	3.2±0.19	49±3	2.67 <sup>b</sup> ±0.11	3.06 <sup>b</sup> ±0.04	2.37 <sup>b</sup> ±0.04	77.2±0.7	15±3	238 <sup>b</sup> ±29
8	4.2±0.17	68±1	4.68 <sup>a</sup> ±0.16	3.35 <sup>a</sup> ±0.05	2.60 <sup>a</sup> ±0.05	77.8±0.4	18±40	280±38	2.0±0.15	32±1	2.62 <sup>b</sup> ±0.18	3.01 <sup>b</sup> ±0.03	2.31 <sup>b</sup> ±0.04	76.8±0.4	18±4	252±52
<b>Farm C</b>																
4	2.3±0.11	38±1	5.26 <sup>c</sup> ±0.03	3.49 <sup>c</sup> ±0.03	2.73 <sup>c</sup> ±0.02	78.1±0.4	12±20	289 <sup>c</sup> ±36	3.8±0.76	62±1	2.96 <sup>d</sup> ±0.06	3.13 <sup>d</sup> ±0.03	2.42 <sup>d</sup> ±0.03	77.5±0.4	15±40	139 <sup>b</sup> ±25
62	3.2±0.23	50±2	4.89 <sup>a</sup> ±0.08	3.36 <sup>a</sup> ±0.07	2.61 <sup>a</sup> ±0.07	77.7±0.6	27±26	226 <sup>a</sup> ±46	3.1±0.18	50±2	2.58 <sup>b</sup> ±0.09	3.09 <sup>b</sup> ±0.05	2.39 <sup>b</sup> ±0.04	77.4±0.5	31±23	149 <sup>b</sup> ±26
2 <sup>#</sup>	3.8±0.86	69±4	5.05±0.19	3.33±0.19	2.59±0.18	77.7±0.9	32±19	234±21	1.7±0.81	31±4	2.71±0.16	3.08±0.11	2.37±0.08	77.1±0.1	26±18	118±23

Note: \* within a row for each component analyzed followed by the same letter are not significantly different ( $P < 0.01$  for a–b and  $P < 0.05$  for c–d); # not covered by statistical analysis.

**Table 2** Mean components of bulk milk (CF + DF) by farm and separation ratio

Farm	Separation ratio per farm	Total milk/( $\times 10^3$ kg)	Fat/%	Protein/%	Casein/%	(Cas/Prot)/%
A	40:60	5.8 $\pm$ 0.63	3.75 $\pm$ 0.21	3.18 $\pm$ 0.06	2.48 $\pm$ 0.03	78.1 $\pm$ 0.50
	50:50	6.1 $\pm$ 0.35	3.75 $\pm$ 0.09	3.17 $\pm$ 0.06	2.46 $\pm$ 0.05	77.7 $\pm$ 0.42
	70:30	6.8 $\pm$ 0.11	3.72 $\pm$ 0.05	3.09 $\pm$ 0.01	2.43 $\pm$ 0.02	78.4 $\pm$ 0.40
B	40:60	6.4 $\pm$ 0.14	3.58 $\pm$ 0.25	3.16 $\pm$ 0.03	2.44 $\pm$ 0.03	77.4 $\pm$ 0.57
	50:50	6.4 $\pm$ 0.24	3.74 $\pm$ 0.08	3.21 $\pm$ 0.03	2.49 $\pm$ 0.03	77.6 $\pm$ 0.57
	70:30	6.1 $\pm$ 0.28	3.80 $\pm$ 0.14	3.20 $\pm$ 0.04	2.48 $\pm$ 0.04	77.4 $\pm$ 0.37
C	40:60	6.1 $\pm$ 0.17	3.83 $\pm$ 0.06	3.26 $\pm$ 0.01	2.54 $\pm$ 0.02	77.7 $\pm$ 0.33
	50:50	6.3 $\pm$ 0.32	3.74 $\pm$ 0.07	3.23 $\pm$ 0.06	2.50 $\pm$ 0.05	77.5 $\pm$ 0.50
	70:30	5.5 $\pm$ 0.17	4.21 $\pm$ 0.09	3.23 $\pm$ 0.15	2.51 $\pm$ 0.14	77.5 $\pm$ 0.56

### 3.2 Vacuum stability

The fluctuation in vacuum pressure in the milkline is a parameter that may be affected by changes in the design and configuration of milking parlors, as well as increasing mechanization and automation levels. To verify that the implementation of the milk separation system did not compromise the stability of the vacuum pressure during milking, specific measurements were made to verify compliance of an installation with the requirements of ISO 5707:2007<sup>[32,33]</sup>.

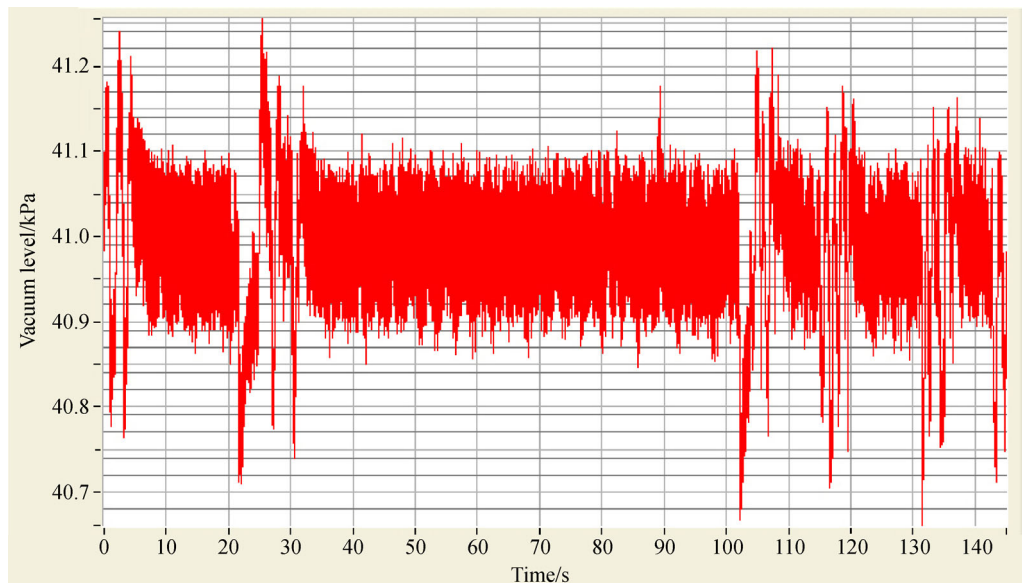
Mechanical tests were performed both during milking and on a milking machine running dry, on each of the farms. The milking-time tests are the most direct indicator of the performance of any milking system<sup>[34]</sup>. At the same time, dry tests are also suitable for field use and permit simulation of different operational incidents (e.g., air admission due to careless operators or liner slip). The

values recorded were in all cases lower than the vacuum fluctuation limit of 2 kPa under ISO 5707:2007 as the maximum limit to guarantee an optimal milking (Fig. 2).

The results of milking-time tests are shown in Table 3. The modifications made on the milking systems did not, therefore, compromise the quality of milking in terms of vacuum stability.

### 3.3 Cost analysis of Afimilk MCS system implementation

The costs of commercial implementation of the systems were also analyzed to provide information for meaningful extension of this innovative technology to the dairy industry. The operators of the dairy farms involved in the study have been interested in a modernization their milking parlor to achieve the objectives of the research. The total cost incurred by each farm has been adjusted according to the size of the milking parlor, the number of milking cows



**Fig. 2** Vacuum flow in the milkline during milking. From the analysis of the diagram it is possible to determine the mean value of the fluctuations and to evaluate the progress of the milking.

**Table 3** Mean vacuum level fluctuations (kPa) in milklines of each milking parlor used in the study

Farm A		Farm B		Farm C	
Sensor 1	Sensor 2	Sensor 1	Sensor 2	Sensor 1	Sensor 2
0.8	0.8	0.4	0.4	0.3	0.4

Note: Sensor 1, CF milking; Sensor 2, DF milking.

and the annual milk production. This allowed for comparisons of costs between farms. For the purchase and installation of the AfiMilk MCS system, a total of 68808 EUR was spent by Farm A, 134322 EUR by Farm B, and 83619 EUR by Farm C (Table 4).

The new implementation included two cooling tanks for milk separation on site. For this reason, a second cooling tank, with a capacity of 5000 L and a cost of 25212 EUR was purchased by each farm. The installation of the AfiMilk MCS system entailed minor building and electrical works with an average cost per farm of 1933 EUR for structural work and about 3000 EUR for electrical work. Dividing the total cost incurred by the number of raised cows, the average cost per head was 236 EUR. The average total cost per milking stall was about 5999 EUR, and this ranged from 5478 EUR for Farm B to 6268 for Farm C.

## 4 Conclusions

The AfiMilk MCS system allowed for separation of milk with high fat and protein concentration. The milk separation tests conducted on three dairy farms indicated that the separated milk had high coagulation properties compared to the bulk milk with increased fat of 18%–43% and protein of 3%–7%. The implementation of the AfiMilk MCS system in established milking parlors did not adversely affect the performance of the mechanical milking. Therefore, over a period of years a farm could improve its technological level with relatively minor structural and mechanical investments. The innovative systems installed in the milking parlors also allowed farmers to make more informed decisions for improving herd management. Specifically, the data regarding the individual somatic cell counts enabled cows with mammary gland infections to be promptly identified and monitored. This will help to reduce the number of cows which may be removed for sanitary issues. Furthermore, individual milk yield records represent important data to support decision making, such as for breeding programs,

nutrition and animal welfare.

Dairy farms which adopt smart technologies may increase their competitiveness in the market and diversify the products they sell. The evaluation of the systems in this study has provided valuable data on reliability and efficiency of real-time milk separation and demonstrated that the system can be affordably implemented. Future research could explore new opportunities for milk separation, such as separating milk with different levels of nutraceutical components.

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**Compliance with ethics guidelines** Maria Caria, Giuseppe Todde, and Antonio Pazzona declare that they have no conflicts of interest or financial conflicts to disclose.

All applicable institutional and national guidelines for the care and use of animals were followed.

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**Table 4** Summary of costs (EUR) for the installation of the AfiMilk MCS system, including construction and electrical work

Farm	Construction works/EUR	Electrical works/EUR	AfiMilk MCS/EUR	Milk tank/EUR	Total/EUR	Average cost per head/EUR	Average cost per milking stall/EUR
A	2000	4000	68800	25200	100000	200	6200
B	1800	3000	134300	25200	164300	274	5500
C	2000	2000	83600	25200	112800	235	6200

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