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MODELLING THE MILK PRODUCTION AND ECONOMICS IN A DAIRY FARM

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Abstract

The paper focuses on factors affecting the economics of milk production based on modelling future effects of present managerial decisions. Using the innovative interactive decision tool we identify key future economics of a dairy farm based on relevant data of herd structures in Slovakia. We introduce EkonMOD milk tool assisting dairy farm managers in Slovakia to better understand the dynamics of the herd structure and to improve the interpretation of economically sensible decision-making on key variables as well as trade-offs respecting the farm´s specific limitations along with carbon footprint mitigation agenda.

We evaluate a sample dairy farm from the economic and performance indicator datasets of the NPPC, referring to semi-intensive dairy farm. If the age at first calving is reduced from 30 down to 24 months, the dairy could expect additional heifers for potential sale, growth, or culling pressure on the lactating herd. This scenario means that in the first two years heifer development is emphasized, expenses in feed and management are decreased by 47,520 € per year, and 53,750 € worth of heifers are sold, bringing the total potential income for those two years to 101,270 €. The reduction of Age at first calving (AFC) in the what-if scenario 1 also reduced the number of heifers needed for replacement from 290 to 269 heifers, also having the positive impact on the profitability resulting from this interrelations. In the what-if scenario 2 the AFC remained the same as in what-if scenario 1 (also the culling rates for the first and next lactation cows) meaning that the number of replacements needed was without any change.

Keywords: *dairy farm, milk, decision tool, production*

JEL classification: *Q02, Q12, O31*

1 EU dairy farming and diary economics

EU dairy farming systems are increasingly faced to the ongoing structural changes associated with the shift to large intensive systems, being more profitable and competitive in the global level. According to study of Burrell and followed by Dries the smaller, locally operating milk producers and their producer associations diffused all over Europe, are substituted by more concentrated and leading to an almost complete integration of these associations into the integrated downstream cooperative and MNC (Multinational corporations) managed by processing industries. (Burrell, 2004; Dries et al., 2009).

EU dairy production can be broadly divided into five main economic-technical systems, however still with significant variation within each system. As reported in this study[2] of the EU intensive high input-output system is dominantly located in Netherlands, England, France, Sweden, Denmark and Germany, accounting for the majority of dairy cow numbers and milk output. The average herd size and stocking rates are relatively high. The average herd age tends to be young which implies a relatively high replacement rates (CEAS, 2010).

The key point when considering the optimal housing system, nutrition strategy, microclimatic levels and other related issues is categorisation according to age of animal. In general, the dairy herd age metric are as follows (Brestenský and Mihina, 2006):

- Calves (from born to 6 month of age)
- Young cattle rearing period (heifers from 6 months till first calving)
- Bull fattening (if present on farm)
- Cows (from first calving till culling)

When considering the animal physiological requirements the more detailed age categorization into subgroups is needed. The main nutrition-based structure involves three main subgroups:

- calves during prophylactic rearing period (critical colostrum intake)
- calves in milk feeding till weaning
- calves from weaning until the age of 6 months

[2] Available at ec.europa.eu/environment/agriculture/pdf/dairy.pdf

Replacement heifer breeding is also divided into three main subgroups:

- Heifer rearing until 12 months
- Heifer rearing from 12 until 24 months (usually until the 5.-7. month of pregnancy)
- Pregnant heifers from the 5.-7. month of gravidity till the first calving

Dairy cow herd grouping according to the reproductive cycle is being categorised as follows:

- Productive cows (from colostrum till dry period)
- Dry cows (from dry off until the beginning of calving)
- Cows in calving period (preparation for calving, calving and colostrum production)
- First calving heifers (special category)

1.1 Economic sustainability of dairy production

The dairy sector, and agriculture in general, faces three key challenges: the need to produce more in order to feed a growing world population, to produce something different (adjust to consumer demands for food and new services) and, last but not least, to produce better (in respect of the environment, ecology and efficient resource use). The latter challenge is often the first to be associated with sustainability, although sustainability comprises not only the environment, but also includes social (people) and economic (profit) dimensions (De Jong, 2013). The importance of animal-source foods in maintaining the health and nutritional status of inhabitants of developing countries, for whom the supply of high-quality protein is often limited, is well recognized. A common description of sustainability is the ability of a system, a firm or a sector to survive in the long run. The concept of resilience indicates the ability of a system, firm or sector to maintain its structural and functional capacity after a disturbance or shock (Perrings, 1998). Resilience is evidenced by an ability to recover and persist. According to Garmestani et al. (2006) the most resilient industries will be those with functions spread across the range of firm size.

1.2 Decision support tools for dairy farm management

Integrated information tools will be a major contributor in the realization of a sustainable development, although receiving only limited attention in current research generally (Melville, 2010; Korte et al., 2012), and especially in agriculture (Aubert et al., 2012). Agricultural production decision-making is becoming

more complex, due in part to increased competition caused by the globalization of agriculture and the need to adopt more sustainable farming practices (Rogers et al. 2004). The decision support tools typically have quantitative output and place emphasis on the end user for final problem solving and decision making (Newman et al. 2000). Software applications can facilitate effective farm management by recording data efficiently, analysing it, and generating a series of evidence-based recommendations. The benefits of using a decision support tools are that it can improve individual productivity, improve decision quality and problem solving, as well as facilitate interpersonal communication. It can also improve decision-making skills and increase organizational control (e.g. Power, 2002; Turban et al., 2007).

Optimal replacement decisions are cited as one of the most important factors affecting dairy farm profitability (van Arendonk, 1985), and these decisions are directly affected by fluctuations in milk price, salvage values, and replacement costs. Culling decisions are based primarily on milk production and partially on health status. Despite their economic importance, culling decisions are often made in a nonprogrammed fashion and based partly on the intuition of the decision maker (Lehenbauer and Oltjen, 1998). According to Compton et al. (2017) dairy industries and farmers need benchmarks for culling and mortality against which they can compare themselves, as well as improved understanding of the extent of any change and of any associated factors.

2 Data and Methods

The economic and production input data was obtained from database developed by National Agricultural and Food Centre, Research Institute for Animal Production Nitra, the Institute for Animal Husbandry Systems, Breeding and Product Quality, best referring to the conditions in Slovak dairy farming systems. This detailed dataset (since 2000) enables the correct assessment of real-farm problems and opportunities based on farming system applied. Based on these data, the dairy sector is able to define the points of interest (for economic optimization and greenhouse gas mitigation agenda) with regard to specific dairy farming systems used.

The result of complex evaluation of economic and production indicators is the assessment of the dairy farm efficiency. This approach also allows comparison between peer operations as well as, benchmarking on the farm level. The metric included in the evaluations are based on parameters describing the calves and replacement heifer rearing cost and production metric of liveweight and weight gains. The following list of parameters is according to Daňo et.al (2007)

fundamental to construction of dairy herd turnover economics evaluation and projections.

Parameters:

P_{NC} – New-born calf price
C_{NC} – New-born calvf cost
C_{SC} – Cost to rear a selected calf
C_{WC} – Cost to rear a weaned calf 6 (8) months
W_{WC} – Average liveweight of weaned calf 6 (8) months
C_{SH} – Cost to rear a selected heifer
C_{PH} – Cost to rear a pregnant heifer
C_{SB} – Cost to rear a selected bull
C_{CH} – Cost to rear a first calving heifer

When assessing the complex economic evaluation procedure the equations 1-8 are crucial. They represent the rationale of determining the cost of production within and during the rearing periods along with performed farm decisions in evaluated time period. They are supportive when establishing the framework for milk production system and husbandry systems optimization in line with consistency plans for economic and non-economic volatility. This also implies updating the break-even point of productions and to cycle this calculations to ensure that the dairy operation outputs and performance indicators meet the necessities determined by the market. Setting the minimal milk price to reach zero profitability or minimal milk yield per cow or total costs per cow per year then support the farm management to agile responds.

Equations for parameters:

$$1.\ C_{NC} = W_{NC} * P_{NC}$$

$$2.\ C_{SC} = \frac{W_{SC} - W_{NC}}{G_{CL}} * C_C + P_{NC}$$

$$3.\ C_{WC} = (180 * C_C) + P_{NC}$$

$$4.\ W_{WC} = (180 * G_{CL}) + W_{NC}$$

$$5.\ C_{SH} = \frac{W_{SH} - W_{WC}}{G_{HL}} * C_{YC} + C_{WC}$$

$$6.\ C_{PH} = (x_1 * C_{YC}) + [(x_0 - x_1) * C_{PH}] + C_{WC}$$

where:

$x_1 = A_{FC} - 330\ days$

$$x_0 = \frac{W_{SH} - W_{WC}}{G_{HL}}$$

$$7.\ C_{SB} = W_{SB} * C_{FBW} = \frac{W_{SB} - W_{WC}}{G_{BL}} * C_{FB} + C_{WC}$$

$$8.\ C_{CH} = (150 * C_{PH}) + (x_1 * C_{YC}) + C_{WC}$$

Where:

C_C –Total cost per feeding day of calf
C_{YC} –Total cost per feeding day of young cattle
C_{PH} –Total cost per feeding day of pregnant heifer
C_{FB} –Total cost per feeding day of fattened bull
C_{FBW} –Total cost per kg of liveweight of fattened bull
W_{NC} –Average liveweight of new-born calves
W_{SC} –Average liveweight of selected (slaughter) calves
W_{SH} –Average liveweight of selected (fattened) heifers
W_{PH} –Average liveweight of selected (pregnant) heifers
W_{SB} –Average liveweight of selected bull
G_{CL} –Average liveweight daily gain of calves
G_{HL} –Average liveweight daily gain of replacement heifers
G_{BL} –Average liveweight daily gain of fattened bulls
A_{FC} –Average age at first calving

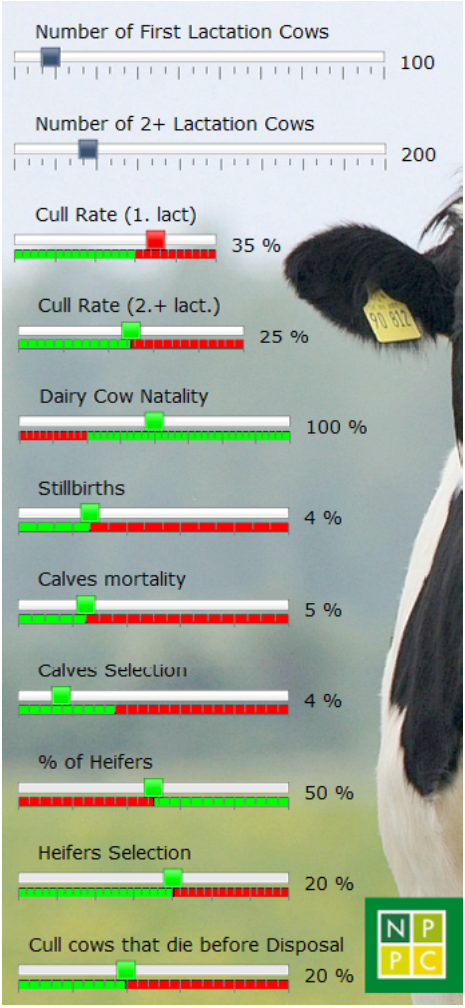
3 Results and Discussion

Resilient livestock production requires locally tailored solutions. Sustainable dairy farming is dependent on the agility of management to continuously tailor the operation according to the market projections, output and input price volatility, with respect to the animal welfare standards. The decision support tool concept for dairy farm managements can be used to evaluate the economic consequences of different on-farm strategies.

Number of heifers needed for replacement we calculated by using several herd specific metrics: If the annual replacement rate of first lactation cow depicted in Figure 1 is set to 35%, and 25 % for remaining stages of lactations in a 300 head herd, a minimum of 170 heifers in the pool, assuming a 4% attrition factor for stillbirths, 100 % dairy cow natality, 5 % mortality of calves. With selection of calves indicator set to 4 %, 50 % ratio of heifers born, heifer selection at 20 %, culled cows that die before disposal set to the value of 20 % and average age at first calving (AFC) 24 months, proximately 64 pregnant heifers are needed. When calving is delayed to an age greater than 24 months, heifers are accumulating in

the replacement pool. For every one month increase in the age at calving over 24 months, the replacement inventory numbers are increasing at a rate of 4.7% in this model. This figure takes into account the inventory of heifers from birth through calving. Therefore, if a herd is calving 28 month old heifers with an average culling rate of first lactation cows 35 % and remaining cows in herd with 25 %, the number of replacement heifers on the farm is now increased from 170 to 199 heifers (Table 1). This equates to 29 additional heifers or an increase of 17 % in the total number of heifers consuming feed, labour, fuel, facilities, and management. The tables below demonstrate the increase in heifers needed at various culling rates (Table 2) and the relationship between the culling rate, age at first calving, and increasing heifer inventory (Table 3). Calving older heifers is subtracting money from profitability. Producers should raise only the number of replacement heifers needed, unless the additional heifers will be marketed (Bailey et al.).

Figure 1 **EkonMOD milk model calibration**



Source: Záhradník and Pokrivčák, 2016.

Table 1 **Number of replacement for each age at calving in a 300 cow herd**

Months	24	26	28	30	32	35
Replacement heifers	170	185	199	213	227	249

Source: Own calculations.

Note: Total heifer inventory numbers for varying herd sizes at a 35% replacement per year for first lactation cows and 25 % replacement per year for cows at remaining lactation stages. Other rearing parameters are taken from the following assumption: 4% stillbirths, 100 % dairy cow natality, 5 % mortality of calves, selection of calves 4 %, 50 % ratio of heifers born, heifer selection 20 %, culled cows that die before disposal 20 %.

Table 2 **Number of replacement heifers for various culling rates**

Culling Rate	Increase in heifer pool numbers over 24 month calving age ^)
25/35*	170 (20 surplus heifers) (32^) = 202** (2 deficit heifers)
26/36*	176 (17 surplus heifers) (45^) = 221** (6 deficit heifers)
27/36*	180 (15 surplus heifers) (46^) = 226** (8 deficit heifers)
27/37*	182 (14 surplus heifers) (47^) = 229** (9 deficit heifers)
27/38*	184 (13 surplus heifers) (48^) = 232** (11 deficit heifers)

Source: Own calculations.

Note: Calving at 24 Months of Age. *Culling rates for second and following lactations/culling rates for first calving heifers. Other rearing parameters are taken from the following assumption: 4% stillbirths, 100 % dairy cow natality, 5 % mortality of calves, selection of calves 4 %, 50 % ratio of heifers born, heifer selection 20 %, culled cows that die before disposal 20 %. **Increase in heifer replacement numbers for various culling rates in 300 cow herd: First calf heifers calving at 30 months.

The current research indicates an average cost to raise a heifer 1824 € (Michaličková et al.) A herd of 300 lactating cows with a culling rate of 25/35 % will need to calve 88 heifers per 12 months. If the average calving age is 30 months, the increase in expenses is approximately 540 € per heifer for those 6 months over goal. This transforms to 47 520 € loss per year in extra labour, feed and fuel. An additional loss in calving heifers at more than 24 months of age is the increase in heifer inventory numbers (Table 42). If producer A is calving heifers at 24 months of age per 300 cows and producer B is calving at 30 months of age, producer B will have additional heifers in his replacement pool to meet the same culling rate as

producer A. The higher AFC accumulates the heifers in inventory. For each additional month over goal of 24 months, 4.7% more heifers are needed in replacement inventory in this model. If producer A needs 171 heifers in his heifer inventory for a 24 month turnover of heifers (from born to calving). Producer B, to meet the same culling rate, will need 214 heifers on his farm. These 43 additional heifers are unnecessarily consuming feed and management (Table 42). Returns from this period down to 24 months could also represent generated income. If the age at first calving is reduced from 30 down to 24 months, the dairy could expect these additional heifers for potential sale, growth, or culling pressure on the lactating herd. This scenario means that in the first two years heifer development is emphasized, expenses in feed and management are decreased by 47,520 € per year, and 53,750 € worth of heifers are sold, bringing the total potential income for those two years to 101,270 € (Table 43). Dairymen should not anticipate reducing the age to calving in several months, as experience indicates that it takes at least 18 to 24 months to decrease age at calving to a goal of 24 months (Bailey et al.).

Table 3 **Economic impact of changed input variables**

Form for estimating heifer rearing economics for a 300 cow herd:
Cost of raising a heifer to 24 months of age = **1900€**
Cost per Month over 24 months in additional expenses = **90€**
Herd at **26/36%** culling rate
Herd calving heifers at 30 months
6 months over goal of 24 months
6 months***90** € = **540 €** per heifer per year
Calving **88** heifers in 12 months @ **540 €** additional cost = **47,520 €**

Transition to reduce age at calving to 24 months of age
Reduced to **24** month age at first calving would need less heifers
See Table 1 (reduce inventory from 213 to 170 heifers or 43 heifers over 2 years) heifers selling for 1250 €

1250 €*43 surplus heifers 1. and 2. year = ****53,750 € total over 2 year transition period**

Source: Form adapted from Bailey et al., own calculations.

Note: **One time transition recovery of income decreasing from 30 Months to 24 Month. Typically accomplished over a 2 year period of time

Sample farm approach

We use the application **EkonMOD milk** tool when supporting the management decision. Moreover, we present the sensitivity analysis feature of the tool.

We run several what-if scenarios and assess the impact on dairy farm performance.

We consider sample dairy farm from the economic and performance indicator datasets of the NPPC, **referring to a typical semi-intensive dairy farm**. The economic impact of decreased AFC and improved indicators during rearing period are summarized in Table 4. The two alternative management approaches are considered. The sensitivity analysis in scenario 1 and 2 represent a typical problem occuring in dairy operation. The sample dairy farm used in this evaluation run an operation with 423 dairy cows. The culling indicator for first lactating cows reaching 36 %, and on second a next lactations 30 % on average. The natality of cows is 95 %, with 7 % stillbirth rate and 11 % calve mortality. Calves selection at the level of 14 % with ratio of heifers born 50 % and 20 % of cows dying before disposal resulted in a need for 290 heifers (from birth till calving) to maintain constant herd size. This performance is related to the 25.8 months of AFC (789 days).

However, the operation did not fully meet the requirements for replacement heifer internally. The performance resulted in 31 heifer deficit, implying the purchasing those heifers from external sources on the market or degreasing the herd size. The what-if scenario considers the decrease of average AFC in this dairy operation to 24 months (733 days). This management adjustment will lead to reduction of heifers inventory needed for replacement. The preposition will decrease the amount of heifer need for replacement to 269 and parallel dilute the deficit to only 21 heifers.

The what-if scenario 2 provides a next step in sensitivity analysis assuming improvements in rearing performance. The stillbirth rate decrease from 7 % to 4 %, calves mortality indicator decrease from 11 % to 5 % and calves and heifer selection decrease from 14 % to 9 % and 20 % to 18% respectively, will cumulatively results in having 3 additional heifer for sale, while the number of heifers needed for replacement remaining the same.

Table 4 **Sensitivity analysis – AFC and heifers (calves) rearing period**

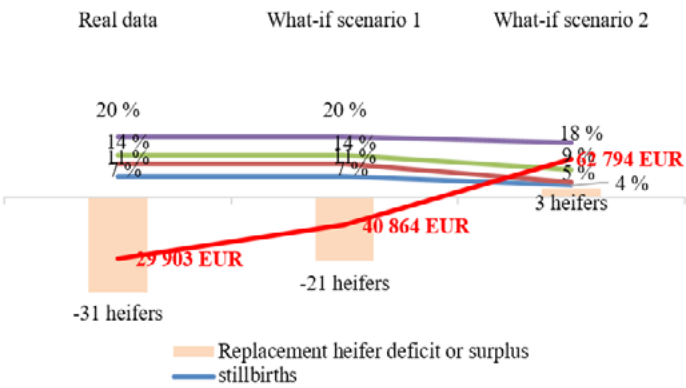
	Real data	What-if scenario 1	What-if scenario 2
Dairy cows numbers	423	423	423
Culling (1. lactations)	36%	36%	36%
Culling (remaining lactations)	30%	30%	30%
Dairy cow natality	95%	95%	95%
Stillbirths	7%	7%	4%
Calves mortality	11%	11%	5%
Calves selection	14%	14%	9%

	Real data	What-if scenario 1	What-if scenario 2
ratio of heifers born	50%	50%	50%
Heifer selection	20%	20%	18%
culled cows that die before disposal	20%	20%	20%
AFC (days)	789 days	733 days	733 days
Number of heifers needed for replacement	290	269	269
Replacement heifers surplus or deficit	-31	-21	3

Source: Own calculations.

Moreover, we can assess the financial aspects of this analysis. If we consider price for culled cow 590 €, cost to raise a heifer 1500 €, price for purchased heifer 1065 € in this operation, the real data case yielded the economic result of 29 903 €. The what-if scenario 1 decreasing the AFC by 56 days will generate 10961 € of additional profit and the what-if scenario 2 optimizing the rearing period resulting in 62 794 € profit, which is almost doubling the original economic result of the sample dairy farm. The analysis is depicted in Figure 2.

Figure 2 **Economic analysis – EkonMOD milk results I.**

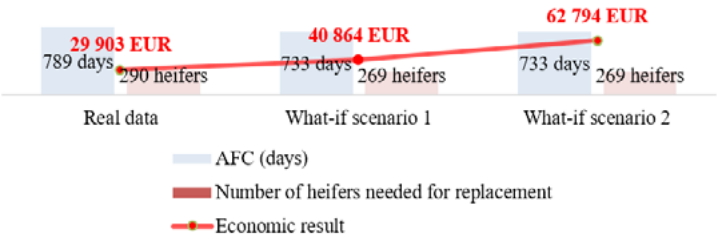


Source: Own calculations.

The figure 3 outlines different perspective on the same situation within the sensitivity analysis. The reduction of AFC in the what-if scenario 1 also reduced the

number of heifers needed for replacement from 290 to 269 heifers, also having the positive impact on the profitability resulting from this interrelations. In the what-if scenario 2 the AFC remained the same as in what-if scenario 1(also the culling rates for the first and next lactation cows) meaning that the number of replacements needed was without any change. However, the improved performance during rearing period contributed with surplus heifers to the financial benefits doubling the original value coming from the real data case.

Figure 3 **Economic analysis – EkonMOD milk results II.**



Source: Own calculations.

The results for any input change proposed is easy accessible, without any need for additional calculation or script procedure, and visualised by interactive dashboard. Moreover, the application outcomes are more clearly visible, also respecting the interrelations logics and methodology used. To go more in detail, we will move to add more managerial scenarios to the AFC sensitivity analysis and see the economic results for this modifications.

We have dealt with the optimal bodyweight (BW) of first calving heifers given the specific AFC. This structured analysis underpins the wider framework of economic optimization of individual dairy production system. The previous work in the sensitivity analysis documented that lower AFC implies fewer replacement heifer needed. However, the reduction schemes are very farm dependent and directly linked to the intensity of calves and heifer growth. The critical point is the optimal combination of daily weight gain leading to the optimal body condition score. The optimal BW of first impregnated heifers should vary between 300-360 kg reaching approximately 55 % of mature cow BW. Moreover, heifer should reach 610 kg of BW when first calving. Every 1 kg below this threshold value implies 2.5 kg reduction in milk production in the first lactations (Fetrow et al., 1986).

4 Conclusion

We have evaluated a sample dairy farm from the economic and performance indicator datasets of the NPPC, referring to semi-intensive dairy farm. If the age at first calving is reduced from 30 down to 24 months, the dairy could expect additional heifers for potential sale, growth, or culling pressure on the lactating herd. This scenario means that in the first two years heifer development is emphasized, expenses in feed and management are decreased by 47,520 € per year, and 53,750 € worth of heifers are sold, bringing the total potential income for those two years to 101,270 €. The reduction of AFC in the what-if scenario 1 also reduced the number of heifers needed for replacement from 290 to 269 heifers, also having the positive impact on the profitability resulting from this interrelations. In the what-if scenario 2 the AFC remained the same as in what-if scenario 1 (also the culling rates for the first and next lactation cows) meaning that the number of replacements needed was without any change. However, the improved performance during rearing period contributed with surplus heifers to the financial benefits doubling the original value coming from the real data case.

The 172 heifers calving per year at the age of 789 days with BW reaching only 80 % will generate an economic loss -35 € on a per cow basis. If the management could improve the performance during the rearing period of both calves and heifers by reducing the average AFC to 733 days (24 months), the economic loss will be only -25 € per cow (reduction 40 %). Moreover, if the dairy farm management could increase the BW of first calving heifers from 80 % to 84 % of average BW of mature cow in the herd (assuming optimum at 85 %), the economic loss will now be only -6 € per cow (reduction 70 %).

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