# DairyVIP: a model to compare the economic consequences of management decisions on dairy farms

**De Vries, A.**
Department of Animal Sciences, University of Florida, Gainesville 32611, USA

## Abstract

DairyVIP (Dairy Value Iteration Program) is a computer program that optimizes breeding and replacement decisions for individual cows and calculates many herd statistics for optimally managed cows. The program allows users to evaluate the economic consequences of, for example, improvements in reproductive efficiency, greater milk production per cow, or changes in prices. The user-interface is developed in Microsoft Excel. First, five input sheets allow the user to enter data on milk production, reproduction, bodyweights, involuntary replacement, and prices. These data are then used by the optimal policy module, which calculates the optimal breeding and replacement decisions for each cow through dynamic programming. Cows are categorized by level of milk production (15 classes), lactation number (12 classes), months in milk (24 classes), pregnancy status (10 classes), and month of the year (12 classes). Next, a Markov chain module simulates a herd consisting of cows that are optimally managed over time and calculates numerous herd statistics. The user-interface then shows over 40 statistics such as profit per cow per year, average days to conception, cull rate, etc. It also displays over 40 graphs showing herd statistics over time, by days in lactation, by month of the year, etc. Two sets of inputs and their results can be compared simultaneously. The optimal breeding and replacement decisions for each individual cow can also be viewed. The computer program is available at http://dairy.ifas.ufl.edu/tools.

## Introduction

Dairy producers, their advisors, and researchers frequently have a need to evaluate the technical and financial effects of changes in reproductive efficiency, milk production per cow, the risk of involuntary replacement, or prices. Changes in any of the inputs affect optimal breeding and replacement decisions and consequently the herd structure. Therefore, the effects of changes in inputs are a combination of changes in herd structure (and prices). Effects can both be technical, such as a change in calving interval or overall cull rate, and financial, such as a change in profitability or the opportunity cost of an involuntarily culled cow.

Studies that address optimal cow replacement decisions were first published over 40 years ago (Jenkins and Halter, 1963) and many studies with independently developed programs have followed. In most studies, the cow replacement (and breeding) decision problem was formulated as a Markov decision process and solved with value iteration (Kristensen, 1994). Value iteration is also known as dynamic programming. The marginal net revenue method may also be used in special cases (Groenendaal et al., 2004).

Computer programs that calculate both optimal breeding and replacement decisions and herd statistics have been around for over 20 years, for example Van Arendonk (1985). These programs first calculate optimal decisions for individual cows and then weigh the probability that such cows exist by their performance, revenues and costs. In this way average results for the whole herd or a group or cows, for example by lactation number, can be calculated.

Groenendaal et al. (2004) pointed out that most of the computer programs developed so far are relatively complicated and not user-friendly. Many of these programs are also compiled with many fixed parameters and therefore limit the number of parameters that can be changed by the user.

There is a need for a computer program that allows the user much freedom in specifying inputs and is user-friendly.

Objective of this study was to develop a user-friendly computer program that optimizes breeding and replacement decisions for individual cows, calculates statistics for herds or groups consisting of optimally managed cows, is user-friendly, and allows the user to change many parameters.

## Methods

A computer program was developed which consisted of three modules (De Vries, 2004). The optimal policy module calculates (optimal) breeding and replacement decisions for individual cows based on the data from the bio-economic module and a dynamic programming algorithm. The herd performance module simulates cows over time and calculates herd statistics based on data from the bio-economic module and the breeding and replacement decisions.

The optimal policy module and the herd performance module were written in C++ and were compiled into one file. The bio-economic module is a Microsoft Excel 2003 (Microsoft Corporation, Issaquah, WA) user-interface where cow performance data and prices are entered or calculated. The Excel spreadsheet and the compiled file automatically communicate with each other through macros and ASCII text files. Figure 1 gives an overview of the sequence of modelling steps.

Input data from the bio-economic module can be saved and read in ASCII text files. The herd statistics and inputs of two different scenarios can be compared simultaneously. The computer program is named DairyVIP (Dairy Value Iteration Program) and is available at http://dairy.ifas.ufl.edu/tools.

| Spreadsheet ➔ | DairyVIP.exe ➔ | DairyVIP.exe ➔ | Spreadsheet |
|---|---|---|---|
| Bio-economic module | Optimal policy module | Herd performance module | Bio-economic module |
| User inputs data:<br>- Cow performance<br>- Decision constraints<br>- Prices | Optimization of breeding and replacement decisions per cow (dynamic programming) | Calculation of group and herd statistics (Markov chain):<br>- Steady state<br>- 3 years into future | Display of results:<br>- Optimal decisions per cow<br>- Herd statistics<br>~ Table<br>~ Figures |

**Figure 1 Overview of sequence of modelling steps in DairyVIP.**

### *Optimal policy module*

The optimal policy module calculates optimal or non-optimal breeding and voluntary replacement decisions for 343,440 cow states. A cow state is a combination of 5 main features that characterize a cow. A cow can be in a state described by one of 15 milk production classes, 12 lactations, 24 months in lactation, nonpregnant or up to 9 months of pregnancy, and 12 months of the year to include seasonality. For example, a cow can be characterized as in the $10^{th}$ milk production class, $2^{nd}$ lactation, $6^{th}$ month in lactation, $2^{nd}$ month of pregnancy, in February. Some combinations are not physically possible and therefore excluded, for example 4 months pregnant while 3 months in lactation. Each state is associated with specific revenues and costs from the bio-economic module.

The optimal policy module uses a dynamic programming algorithm to calculate whether to keep or cull the cow in each state if the slot is occupied and whether to enter or delay entering a replacement heifer if the slot is vacant. Entering can occur immediately after replacement or is one or more months delayed. Heifers are purchased at the time of entering and the supply of heifers is assumed to be unlimited. If the cow is nonpregnant and eligible to be bred, the program also calculates if the cow should be bred or breeding should be delayed. The objective of these breeding and replacement decisions is to maximize the total profits of the slot under steady state (equilibrium) conditions with a cow and her consecutive replacements. Thus, the optimal decisions for each of the 343,440 cow states are calculated.

The value of the decision to keep a cow in a state at least one more month compared to immediately replacing her is called the retention pay-off (RPO). Other values are calculated, such as the value of a pregnancy, and the cost of an extra day not pregnant.

The optimal policy module uses monthly time steps, commonly referred to as stages. Replacement decisions in each state and stage depend only on the performance in the current state and the optimal decisions in the next stage. The dynamic programming algorithm starts with the calculation of optimal breeding and replacement decisions for each state far in the future and then moves backward in time, stage by stage, until the average profit per slot per year is stabilized. At this point the algorithm has converged and breeding and replacement decisions are independent of the arbitrary starting conditions.

The maximum profit per slot per year is obtained when the dynamic programming algorithm is allowed to determine all entering, breeding, and voluntary replacement decisions (the optimal policy). Non-optimal policies can be simulated when one or more restrictions are placed on entering, breeding or voluntary replacement of cows. The dynamic programming algorithm can still be allowed to make some decisions. For example, the option to delay replacement can be enforced or prohibited for each month of the year, while the dynamic programming algorithm still calculates the cull decision for each state given the heifer entering restriction. A policy where the user defines the breeding and voluntary replacement decisions for all states and the months where heifers are entered can also be simulated but the dynamic programming algorithm then has no optimization function.

#### *Herd performance module*

The herd performance module calculates herd statistics resulting from the bio-economic data and the breeding and replacement decisions calculated by the optimal policy module. This module is based on a Markov chain. Markov chains and the Markov decision process were described in more detail for similar cow replacement problems by DeLorenzo et al. (1992). The herd performance module has the same states as the optimal policy module.

The herd performance module simulates one cow (or lack thereof) in one slot from stage to stage, weighing the probability that the cow enters a state (dependent on the decision calculated by the optimal policy module) with her performance, revenues and costs in that state. If the Markov chain is simulated for a sufficiently long time, the state-to-state transition probabilities become stationary and the herd is in steady state. At that point the probability that a cow is in a state (and therefore the herd structure) remains constant. The herd statistics in each stage can be calculated from the weighted performance and events in each state and stage.

It is also possible to start the simulation with an existing herd structure and simulate the herd for three years into the future. The starting herd could be the steady state herd structure that resulted from a different set of inputs, a single heifer purchased today, or the existing herd structure of a real dairy farm. The program then shows the changes in herd statistics in the next three years.

#### *Bio-economic module*

The bio-economic module prepares cow performance data and prices that are used in the optimal policy module and herd performance module. There are six sheets that require user inputs: 1) miscellaneous, 2) prices and decisions, 3) milk, 4) reproduction, 5) bodyweight, and 6) involuntary replacement. After these data are entered, the optimal breeding and replacement decisions are calculated, herd statistics obtained and the results displayed in the bio-economic module.

***Miscellaneous sheet***

The Miscellaneous sheet requires various input data such as the unit of the data (metric or English), labor cost, veterinary cost, feed prices, calf prices, fixed labor cost, and fixed and variable other costs. Feed cost are calculated as a function of month in lactation, bodyweight, milk yield, and feed price. The user also chooses to let the optimal policy module make the breeding and voluntary replacement decisions or formulate a replacement policy based on maximum months non pregnant, minimum daily marginal returns, or minimum daily milk yield.

***Price and decisions sheet***

On this sheet the user enters prices for milk, culled cows, and heifers for 24 months. Prices for the first 12 months are used for the first year of the optimization and simulation. Prices for the last 12 months are used for all years after the first year. These separate prices are useful if the price forecasts for the first year are different from the long run averages and the objective is to calculate herd statistics for the next three years into the future. Herd steady state results are based on the prices for the first year.

PRICE & DECISIONS — DairyVIP

Hide charts

| | | | Breed cows? | Enter heifers? | Heifer price ($) | Cull price ($/kg) | Milk price ($/100kg) | | |
|---|---|---|---|---|---|---|---|---|---|
| Year 1 | 1 | Jan | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jan | Year 1 |
| | 2 | Feb | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Feb | |
| | 3 | Mar | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Mar | |
| | 4 | Apr | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Apr | |
| | 5 | May | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | May | |
| | 6 | Jun | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jun | |
| | 7 | Jul | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jul | |
| | 8 | Aug | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Aug | |
| | 9 | Sep | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Sep | |
| | 10 | Oct | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Oct | |
| | 11 | Nov | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Nov | |
| | 12 | Dec | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Dec | |
| Year 2 | 1 | Jan | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jan | Year 2 |
| and later | 2 | Feb | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Feb | and later |
| | 3 | Mar | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Mar | |
| | 4 | Apr | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Apr | |
| | 5 | May | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | May | |
| | 6 | Jun | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jun | |
| | 7 | Jul | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Jul | |
| | 8 | Aug | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Aug | |
| | 9 | Sep | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Sep | |
| | 10 | Oct | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Oct | |
| | 11 | Nov | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Nov | |
| | 12 | Dec | DECIDE | DECIDE | 1600 | 0.74 | 31.00 | Dec | |

**Figure 2 Price and decisions sheet in the bio-economic module.**

The user also enters decisions about breeding for 24 months. Possible choices are “decide”, “breed”, and “do not breed”. These choices are used in the optimal policy module by the dynamic programming algorithm. The choice “decide” lets the optimal policy module calculate whether breeding or not breeding is the optimal decision. Similarly, for entering heifers the choices are “decide”, “enter”, or “do not enter”. If the choice is “do not enter”, then the optimal policy module will not purchase and enter any heifers in that month to replace the culled cows in the previous month. A fraction of the slots will therefore be vacant.

***Milk sheet***

The Milk sheet requires average daily milk yields for the first three lactations by month of lactation and month of the year. The milk yield in the third lactation is also used for later lactations. Average milk yields must be entered for 24 months in lactation. The user may directly enter daily milk yields. Alternatively, the parameters of the Wood’s incomplete gamma lactation curve for each of the three lactation numbers may be entered. Seasonality can be adjusted separately by entering a percentage adjustment per month of the year. Furthermore, a percentage change or an absolute change may be entered. The computer program will then automatically enter the resulting daily milk yields. A third option is to enter peak milk yield, days in milk at peak milk yield, and 305-day total milk yield. Wood's incomplete gamma lactation curves will be fitted and the estimated daily milk yields will be automatically entered. The effects of pregnancy on milk yields are entered separately. The user enters the reduction in daily milk yield caused by pregnancy per month of gestation and the length of the dry period in months.

***Reproduction sheet***

The Reproduction sheet requires service rates, conception rates, and additional breeding cost by month of lactation and month of the year. Seasonality can be adjusted separately by entering a percentage adjustment per month of the year. No breeding is possible before the start of the 3rd month (day 61) and after the end of the15th month (day 456) in lactation. If a cow conceives at the end of the 15th month in lactation, she will calve at the end of the 24th month after calving. The Reproduction sheet also requires the risk of abortion per month of pregnancy, the minimum voluntary waiting period, the last allowable breeding month, the price per breeding, and labor associated with breeding.

***Involuntary replacement sheet***

The computer program assumes a risk of involuntary replacement in each of the 24 possible months of lactation, even when the optimal decision is to keep the cow. Involuntary replacement is caused by death or severe health problems. The risk of involuntary replacement is entered by month of lactation and month of the year. Seasonality can be adjusted separately by entering a percentage adjustment per month of the year. In addition, the relative risk per lactation number is entered.

Plan A: noseason.bio: steady state
Plan B: season.bio: steady state

**per slot / year** — Year 1, per slot / year

| | plan A | plan B | plan A - B | | plan A | plan B | plan A - B |
|---|---|---|---|---|---|---|---|
| milk sales | 3023 | 2730 | 293 | days to end VWP | 61 | 63 | -1 |
| cow sales | 76 | 73 | 3 | days to first service | 85 | 84 | 2 |
| calf sales | 196 | 188 | 8 | days to conception | 158 | 148 | 9 |
| *total revenue* | *3296* | *2991* | 305 | days to last service | 456 | 455 | 1 |
| feed cost | 1464 | 1358 | 106 | calving interval (mo) | 14.2 | 13.9 | 0 |
| breeding supply cost | 33 | 30 | 3 | open days | 154 | 148 | 5 |
| heifer purchase cost | 486 | 467 | 19 | pregnancy rate | 16% | 17% | -1% |
| veterinary cost | 76 | 73 | 3 | value of new pregnancy | 354 | 344 | 10 |
| inv. culling loss | 0 | 0 | 0 | cost of loss of pregnancy | 841 | 831 | 10 |
| variable labor cost | 418 | 396 | 22 | breeding cost / preg | 38 | 35 | 2 |
| variable other cost | 182 | 173 | 9 | cost of extra day open | 2.25 | 2.42 | -0.17 |
| fixed labor cost | 0 | 0 | 0 | overall cull rate | 29% | 30% | 0% |
| fixed other cost | 456 | 456 | 0 | involuntary cull rate | 25% | 25% | 0% |
| *total costs* | *3115* | *2953* | 163 | voluntary cull rate | 5% | 5% | 0% |
| *total profit* | 180 | 38 | 142 | days in milk | 246 | 242 | 4 |
| total fixed cost | 456 | 456 | 0 | value of cow | 1838 | 1801 | 37 |
| revenue - var. cost | 636 | 494 | 142 | cull price | 260 | 260 | 1 |
| cost to maintain herd | 410 | 394 | 16 | dry cow feed cost / day | 1.80 | 1.78 | 0.02 |
| breeding cost | 33 | 30 | 3 | lact. cow feed cost / day | 4.31 | 4.21 | 0.09 |
| milk yield | 9752 | 8800 | 952 | income over feed cost / day | 4.27 | 3.76 | 0.51 |
| | | | | fixed:total cost ratio | 0.15 | 0.15 | -0.01 |
| | | | | milk:feed price ratio | 2.06 | 2.01 | 0.05 |

**Figure 3 The Table sheet shows technical and financial results per cow per year or per 100 kg (lbs) for two different sets of inputs (plan A and plan B).**

***Bodyweight sheet***

Bodyweights for nonpregnant cows for first and greater parities are entered for 24 months in lactation. The additional bodyweight caused by pregnancy is entered separately.

## Results

There are four sheets that display results: 1) table, 2) graphs per month of the year, 3) additional graphs, and 4) individual cow decisions. The bio-economic module shows results of two sets of inputs simultaneously (plan A and plan B).


**Figure 4 The Time sheet shows technical and financial results per month of the year. The first 15 graphs are shown.**

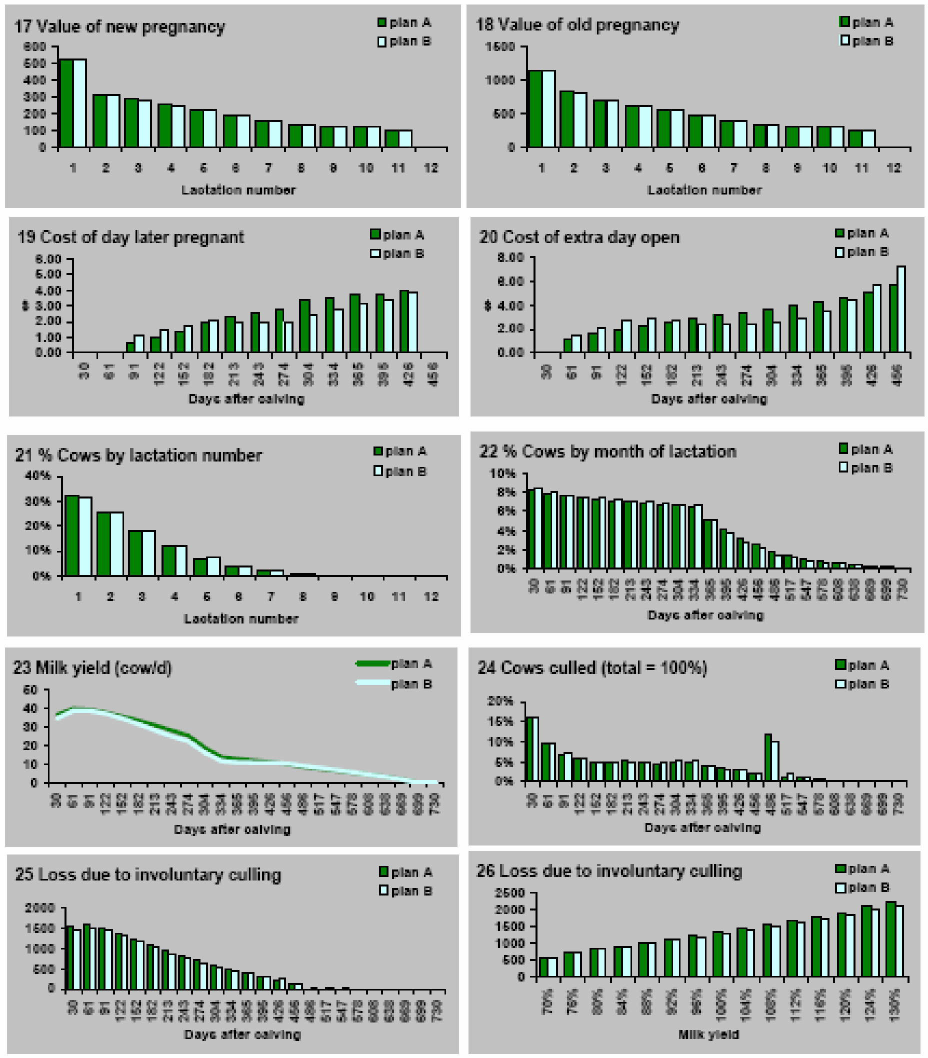


**Figure 5 The Chart sheet shows technical and financial results per milk yield class, days after calving, or lactation number. Graphs 17 through 26 are shown.**

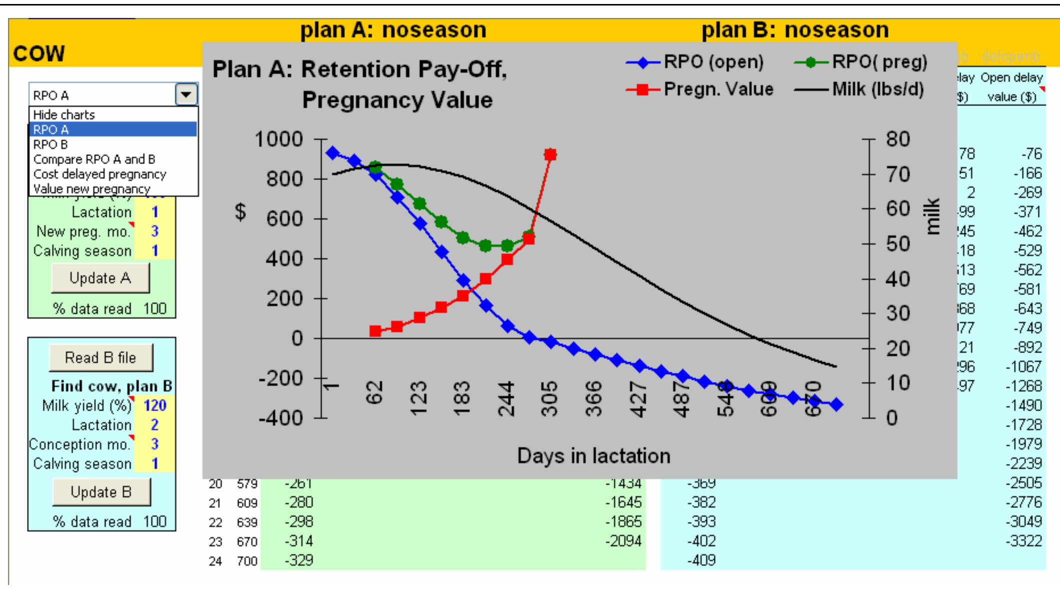


**Figure 6 The Cow sheet shows the retention pay-off (RPO) and value of pregnancy by months in lactation and pregnancy status for an individual cow.**

***Table sheet***

Technical and financial results per slot per year or per 100 kg (or lbs) milk produced are displayed on the Table sheet (Figure 3). The financial results include all types of revenues and costs, as well as profit. Technical results include several measures about reproductive performance, replacement, and feed costs.

***Time sheet***

The Time sheet displays technical and financial results per month of the year for years one to three in graphs (Figure 4). Effects of seasonality are easily observed. Measures include for example profit per month, fraction culled, fraction delayed breedings, pregnancy rate, and average daily milk yield.

***Chart sheet***

The Chart sheet displays technical and financial results for years one to three in various graphs (Figure 5). The breakdown is either by milk yield, days after calving, or lactation number. Measures include for example days to first breeding, days nonpregnant, value of pregnancy, herd demographics, and the economic loss due to involuntary replacement.

***Cow sheet***

The Cow sheet displays the RPO and value of pregnancy by month in lactation for a cow state characterized by milk yield class, lactation number, month of conception, and calving month of the year (Figure 6). The value of a new pregnancy and the cost per day nonpregnant are also shown. Results on this sheet can both be displayed in text format or in graphs.

## Discussion

A computer program developed in Microsoft Excel is now available that optimizes individual cow breeding and replacement decisions and calculates numerous associated herd statistics. The optimal policy module and herd performance module is a C++ compiled file that allows for quick optimization and calculations of herd statistics, typically within 20 seconds. The computer program can be used to provide estimates of costs used in veterinary economics, such as the opportunity cost of an involuntary culled cow or the cost of an extra day nonpregnant.

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