Shed light on dark feedback loops! - The consequences of not recognizing feedback loops for the dominant management logic

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What you see is all there is
Daniel Kahneman

Abstract

This paper deals with feedback loops in mental models of dynamic systems (MMDS). However, untrained individuals fail to recognize most of the loops inherent in by the causal structure they articulate: many loops remain invisible like dark matter. This paper takes the example of recent research concerning the strategic reasoning of vineyard executives. Out of nine participants, only three recognized any loops, but 90% of the inherent loops – identified following the logic of the shortest independent loop set (SILS) - remained 'dark' to them. By identifying the connections between the inherent loops, it is shown that the impact of the dark loops on the majority of variables in their mental models was not recognized. Based on these results, it is argued that decision makers ought to be given qualitative modeling tools for articulation of mental models which automatically detect and visually feed back the SILS loops. Also, the enhanced 'distance ratio' method ought to become able to process 'dark' loops. Eventually, the debate concerning loops in mental models ought to be taken to the larger community of mental model research in management.

Keywords

Keywords: Mental model of dynamic systems, feedback loops, shortest independent loop set, strategic management

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1 Introduction

Steering a firm on an economically sustainable path in a competitive market requires executives to understand and interact with dynamic situations. Multiple decision makers set goals involving the same variables and simultaneously try to achieve them, each affecting the conditions under which the others take their decisions. Each executive's decision policies are based upon how they understand their situation, how they describe the purpose and form of their industry and their firm, explaining their functioning and observed behavior, enabling them to anticipate likely future developments. This description of their activity almost literally conforms to an early definition of "mental model" (Rouse and Morris 1986), as cited in (Mathieu, Heffner et al. 2000), which is much referred to in general mental model studies in management.

Since the complexity of a situation can only be absorbed by a mental model of equivalent complexity (Ashby 1991), these mental models should consist of knowledge structures which are able to represent such complexity. Standard mental model methods lead to maps of attributed causal structures consisting of variables and causal links (Markóczy and Goldberg 1995a). However, the behaviors of the business systems are driven by the feedback loops and their interaction (Forrester 1969; J. Sterman 2000), leading to dynamic complexity (Özgün and Barlas 2015). In models, dynamic systems are represented as sets of interacting feedback loops (S. N. Groesser and M. F. Schaffernicht 2012), which emerge when the change of one variable depends on the quantity of another variable. Therefore, a *mental* model of a dynamic system (MMDS) has three different levels of description: the elements (variables and causal links), the individual feedback loops and the entire model (S. Groesser and M. Schaffernicht 2012).

Contrary to what might be expected according to this argument, many decision makers appear to understand their situation in a way which almost completely lacks feedback loops. This is an observation frequently made by system dynamics modelers working with clients. Of course, if loops are important drivers of a system's behavior, executives who fail to recognize them are in danger of not perceiving important drivers in their decisions (Sterman 1989). This so-called misperception of feedback has been a focus of attention in the literature, and empirical studies suggest it is a widespread problem (Sterman 2010).

Despite of being considered a relevant problem by researchers close to the field of system dynamics, the mainstream mental model literature in management and organizational studies has not yet taken notice of the role of feedback loops (Klimoski and Mohammed 1994; Langan-Fox et al. 2004; Langan-Fox et al. 2000a; Langan-Fox et al. 2000b; Langfield-Smith and Wirth 1992; Markóczy and Goldberg 1995b; Mohammed et al. 2010; Mohammed et al. 2000). In the recent past, the 'distance ratio' method (Langfield-Smith and Wirth 1992; Markóczy and Goldberg 1995b) has been adapted such as to take loops into account. Its representation and analysis of MMDS keeps the advantages of representing models as directed graphs (Langan-Fox et al. 2004), extending the methods for dealing with the three levels (M. Schaffernicht and S. Groesser 2011), calculating an 'Element Distance Ratio' for variables and causal links, a 'Loop Distance Ratio' for every pair of comparable loops and a 'Model Distance Ratio' for the entire set of loops conforming the model. Analysis tools have been developed for the current version of this method (M. Schaffernicht and S. Groesser 2014).

Data from a recent research project about the mental models of winemakers in the Maule region of Chile (Fondecyt 1140638) goes along with the misperception of feedback thesis, but also call attention to an aspect which has not been problematized and discussed as yet: the project finds that the causal structures of the mental models articulated by executives and owners of vineyards contain many more loops than are recognized by the executives. In other words, these executives recognize all the variables and causal links the loops consist of, but they do not recognize their circular nature.

This article focuses on the differences between the 'dark' loops inherent in the model structure – as detected using the logic of the shortest independent loop set (Oliva 2004) - but unrecognized and those recognized by the executives. The differences which appear when comparing the recognized loops with the inherent ones show how little of the feedback structure has been recognized by the owners of these mental models.

When an executive makes plans, these will only refer to what the executive's mental model contains – variables and relationships which are absent from the mental model are not taken into account, hence the initial quote (Kahneman 2011). When feedback loops are not seen, many variables may be mistaken as levers for discretionary management decisions, despite the fact of being subject to the autonomous influence of the loops inherent in the management situation. The data presented here strongly point that way: each of the 47 most relevant variables out of 446 belonged to one or several of 50 loops, but only 5 of these loops have been recognized. Many influential variables are therefore understood in an input-output manner. They may look as if they can be used as levers, but many 'dark'(unrecognized) loops will feed back current decisions into future behavior, and the behaviors will be surprising to the executive who does not see the loops. Just like dark matter is unseen but influences the behavior of the astrophysical universe, dark loops are unseen but influence the behavior of business systems.

Therefore, the existence of 'dark' loops severely reduces the executives' ability to take into account relevant sources of influence, thus diminishing the possibility of basing decision policies on a systematic analysis of the underlying situation.

The article proposes several conclusions:

1) there is a need for tools to support on-the-spot construction of causal maps including automatic loop detection and display;
2) there is also a need to enhance the extended 'distance ratio' method in order to assist comparison between the set of recognized loops and the entire set of inherent looks, so to say to shed light on the 'dark' loops;
3) it is time to open a critical debate in the field of mental model research in management, in order to establish feedback loops as important component of mental models.

The remainder of the article is organized as follows: section 2 introduces the methodical aspects. The mental model data used is presented in section 3. Section 4 elaborates on the data discussing its implications and leading to some new research challenges, before concluding in section 5.

2 Methods

2.1 Elicitation and coding

For inter-subject comparison of mental models, a number of methods and tools have been developed (Langan-Fox et al. 2000a; Mohammed et al. 2000). Oftentimes, researchers elaborate a reference list of available concepts in order to maintain the total number of variables in a range between 15 and 25 (Lim and Klein 2006). However, only in-depth open interviews are able to not preclude participants to articulate causal beliefs only because they are not contained in the previously established concept list (Mohammed et al. 2000) – at the price of increasing the number of elements contained in the elicited mental models.

Therefore, in-depth interviews of one hour have been the data source of this study. The interviews were framed by the question "what do you see coming in the regional wine industry over to coming 5 years or so, and how do you steer your vineyard in that context?" The future-oriented question avoided post-fact rationalizations, but otherwise left the choice of topics up to the interviewee.

The interviews were taped, transcribed and then coded in two iterations - first iteration open, second iteration axial. The coding scheme provided instructions to look out for variables, causal links and feedback loops (M. F. Schaffernicht and Groesser 2015). The resulting data ware mapped as a causal map.

2.2 Representation

A MMDS is represented by a set of variables, causal links (or links) and feedback loops (or loops). A variable is represented by its name. A causal link has a direction and a polarity, which can be either positive or negative (M. Schaffernicht 2010; J. Sterman 2000). Additionally, a link can have a delay mark, when it is significantly slower than the other links to transmit an effect. A loop is a closed sequence of links connecting a series of variables; it has a polarity, which is the consequence of constituting links' polarity and can be either positive or negative. To avoid confusion between loops and links, positive loops are called reinforcing loops and negative loops balancing loops. A reinforcing loop generates exponential behavior, whereas a balancing loop creates goal seeking behavior; failure to recognize feedback loops usually leads to flawed expectations concerning a system's behavior (J. D. Sterman 2000).

The general methodic approach has been published elsewhere (M. F. Schaffernicht and S. N. Groesser 2011) and is partially automated (M. F. Schaffernicht and S. N. Groesser 2014). A specific method has been developed to assure that the aggregation level of the respective MMDSs is comparable. This method selects variables which satisfy one of the following criteria: (1) a minimum number of interviewees mention the variable, (2) the variable is characteristic for an individual interviewee, (3) the variable is an input or output variable in at least one of the MMDSs, describing the business environment or an outcome variable (by aggregating it away, some essential aspect of the interviewee's mental model ceases to be taken into account), or (4) the variable is needed to avoid that a loop contains only one single variable.

Variables which do not satisfy any of these criteria become aggregated: incoming links are redirected to the following variable. For instance, if in the sequence *innovation → new wines → differentiation*, only the first and the last variables are selected, then new wines will be hidden and the MMDS is represented as *innovation → differentiation* [1]. The connection between these two variables is called a 'path' because it is a sequence of links; its polarity is obtained by multiplying the polarities of the constituting links, positive in this case. The path length in the example is equal to 2, and the path will be assigned a weight of 1/length = 0.5. This method therefore redefines sequences of unselected intermediate variables and links as paths; all relevant structural information is maintained because all connections between the selected variables in the original MMDSs and all feedback loops in the original MMDSs are conserved.

2.3 Shortest independent loop set

In models of dynamic systems, most of the variables are contained in one or several loops. However, the data in the current project contradict this statement: only 5 of the 50 loops have been recognized, suggesting an input-output type of reasoning. This also means that the MMDS contain all variables and links to constitute 45 more loops than the recognized set. Since by definition, the interviewee did not indicate the feedback loops he or she did not recognize, a replicable way to identify these unrecognized feedback loops is needed.

Usually, there is a hierarchy of loops, and several relatively short loops combine into larger ones. The total number of loops quickly rises to unmanageable quantities, but if one can determine a loop set such as to assure that each variable and link which belongs to any number of loops are taken into account at least once, then none of the possible behavioral implications of any of the loops is eliminated by the fact of not taking into account the combined loops. Such a set is called an independent loop set (Kampman 1996). The so-called shortest independent loop set (SILS) selects the shortest loops first and thereby assures that

[1] The *names of variables* which belong to an MMDS are printed in *italics* to make clear these are not just words.

unnecessary complexity is avoided (Oliva 2004). Such a loop set is elaborated starting with one variable on a short loop and searching the shortest possible path to come back to this variable; along the path, each link used is marked. Upon returning to the initial variable, if there are any other loops with links unmarked so far, the steps are repeated. If there are no more possible loops, another variable selected and the procedure repeated.

2.4 Sample

The study was located in the Chilean wine industry, where many vineyard executives feel challenged: the country's wine industry has displayed a rapid surge starting in the mid '90, when labor and energy costs were low, but two decades later, the steady rise of costs combined with a market category as "best price" has put growing pressure on margins (Berríos, 2012 #47). According to data gathered by Vinos de Chile (V. d. Chile 2015), the target prices aimed at by Wines of Chile for 2020 (W. o. Chile 2010) appear to be impossible to reach. Under such conditions, two distinct archetypical kinds of business policy come to mind for defending *profits*: **increase** the *price of wine* or **decrease** the *unit costs* – by **increasing** the *sales volume* [2]. Leaning more towards one or the other of these policies depends on how the executive represents his vineyard in the context of the wine industry, in other words: on his mental model.

The study was driven by the question 'what do the mental models of these vineyard executives contain?' of the approximately 300 vineyards in Chile, roughly 100, mostly small to medium sized, are based in the Maule Region. A sample of these regional vineyards has participated in a study striving to measure and analyze their owner's or executive's mental model. An interview-based study is time intensive; therefore, a small sample of vineyards was sought for. The University of Talca in the Maule Region is deeply involved with the regional wine industry by means of its Wine Center. Leading experts from this Center identified a sample of 9 vineyards along two dimensions: innovation oriented versus traditional and small versus medium size. The resulting selection includes vineyards of different sizes (from very small to medium) and ages (from start-up to several generations of family ownership), as shown in the following table:

Table 1: The vineyard sample

Type	**Size**	
	Small	Medium
Innovative	2, 6, 8	1, 7
Mainstream	3	4, 5, 6

[2] Words referring to the **behavior** of variables are printed in **fat** letters to distinguish them from the variables themselves and to make the causal relationships between variables more salient.

3 Data

3.1 Overview

The original MMDS consisted of 446 variables and 2087 links, and the aggregation process lead to aggregated MMDS with a total of 219 variables and 551 links. Table 2 shows the mean numbers of variables and of links for each of the MMDS:

Table 2: Global characteristics of the MMDS

MMDS	Vars	Links	Links/Vars ratio
1	34	62	1.82
2	36	55	1.53
3	26	44	1.69
4	35	63	1.80
5	36	48	1.33
6	52	72	1.38
7	36	51	1.42
8	41	55	1.34
9	53	101	1.91
Mean	38.78	61.22	1.58
SDev	8.70	17.16	0.23

The aggregated MMDS are approximately half the size of the original ones in terms of variables and links, but the average of 38 variables is still greater than what many mental model studies use when they define default variable lists {Lim, 2006 #20}. The number of links is roughly 60% higher than the variable count, indicating than most but not all variables participate in several links. The analysis of the intersections between the variable sets of the respective MMDS lead to the recognition of two groups of MMDS: group 1(G1) contains MMDS 1, 3 and 5, while group 2 (G2) assembles MMDS 2, 4, 6, 6, 7, 8, and 9. Table 3 contains three subsets of variables which are contained in at least half of the MMDS belonging to the respective groups:

Table 3: Variables in the two groups of MMDS

Variables mentioned by both groups (18 variables):	
price of wine, costs, production costs, sales, profits, differentiation, production, dominance of large vineyards, price of grape, local partnerships between vineyards, revenues, marketing costs, marketing efforts abroad, market power of large vineyards, average quality demanded, fair trade, personnel costs, alternatives to wine	
Only group 1 (34 variables):	**Only group 2 (47 variables):**
vineyard size, wine category, economic growth in major markets, distributors, identification with the country brand, associativity, degree of adjustment of company size, international per capita consumption, liquidity, purchase of grapes from other producers, authentic narrative, number of artisan vineyards, wine culture, domestic per capita consumption, identification with the region brand, professionalization	*demand for wine, importance of volume in the majority business model, energy costs, organic vine production, innovation, mechanization, territorial rootedness, production area, profitability, investment in winemaking capacity, quality, consumption per capita, innovative wines, value added, production per hectare, artificial inputs, demand for cellaring, consumer desire for novelties, demand for wine with sustainable production, frauds, natural conditions, leasing of wine cellar, recognizability of the wine, taxes, failures, labor supply, sustainability, rural desertion, time to market*

In terms of the 551 links and paths, only a relatively small fraction is shared by the MMDS of both groups: 138 (25%) are only part of G1, 381 (69%) belong to G2 exclusively, and 32 (6%) links are shared across the groups. An analysis of links and paths is certainly interesting, but beyond the scope of this paper, which focuses on the loops. One relevant finding was that even if the MMDSs of both groups include the *price of wine*, G1 MMDS tend to take it as exogenously driven (by market forces), whereas G2 MMDSs use diverse intra-vineyard variables to influence it.

A look at the loops inherent and recognized in each of the MMDS (Table 4) reveals that 4 of the 9 MMDS have five or more inherent loops:

Table 4: Number of inherent loops per MMDS

MMDS	Loops	Recognized	Dark
1	1	0	1
2	3	0	3
3	5	0	5
4	13	2	11
5	2	0	2
6	14	1	13
7	0	0	0
8	2	0	2
9	10	2	8

It also becomes clear that the inherent loops are mainly ‘dark’ ones, remaining invisible for the interviewee. Consider now the sequences of variables, the polarity (Pol) and delayed links (Del) of the loops. Table 5 also indicates if the loops have been recognized or not (if Rec is 1, a loop has been recognized). The loops are ordered by MMDS:

Table 5: Inherent feedback loops detected by SILS logic

MMDS	Loop ID	Rec	Var Names E	Pol	Del
1	101	0	*distributors → degree of adjustment of company size →*	B	0
2	201	0	*price of wine → innovation → differentiation → price of wine*	B	0
	202	0	*demand for wine → shortage → demand for wine*	R	0
	203	0	*demand for wine → production → shortage → demand for wine*	B	0
3	301	0	*sales → price of grape → distributors → sales*	R	0
	302	0	*sales → liquidity → distributors →*	B	0
	303	0	*sales → total debt with producers → liquidity → distributors →*	B	0
	304	0	*total debt with producers → liquidity → total debt with producers*	B	0
	305	0	*liquidity → debt with third parties → liquidity*	R	0
4	401	1	*price of wine → revenues → profitability → quality →*	R	0
	402	1	*price of wine → revenues → profitability → production → quality →*	R	0
	403	0	*price of wine → production →*	B	0
	404	0	*price of wine → sales → revenues → profitability → quality →*	B	0
	405	0	*price of wine → sales → costs → profitability → quality →*	R	0
	406	0	*price of wine → sales → marketing costs → costs → profitability → quality →*	R	0
	407	0	*price of wine → costs → profitability → quality →*	B	0
	408	0	*price of wine → personnel costs → production costs → costs → profitability → quality →*	B	1

	409	0	*price of wine → personnel costs → mechanization → production →*	R	1
	410	0	*price of wine → sales → personnel costs → production costs → costs → profitability → quality →*	B	1
	411	0	*personnel costs → mechanization → personnel costs*	B	0
	412	0	*costs → energy costs → production costs →*	B	1
	413	0	*costs → personnel costs → production costs →*	B	1
5	501	0	*costs → marketing efforts abroad →*	B	0
5	502	0	*market power of large vineyards → growth rate of big vineyards →*	R	0
6	601	1	*profits → production →*	B	0
	602	0	*profits → profitability → production →*	B	0
	603	0	*profits → production → production costs →*	B	0
	604	0	*profits → price of grape → quality → price of wine →*	R	0
	605	0	*profits → production → quality → price of wine →*	R	0
	606	0	*profits → frauds → quality → price of wine →*	R	0
	607	0	*profits → frauds → production → quality → price of wine →*	R	0
	608	0	*quality → categorization on the market → importance of volume in the majority business model → price of grape →*	R	1
	609	0	*quality → categorization on the market → importance of volume in the majority business model → production →*	R	1
	610	0	*quality → categorization on the market → importance of volume in the majority business model → frauds →*	R	1
	611	0	*categorization on the market → importance of volume in the majority business model →*	R	1
	612	0	*categorization on the market → importance of volume in the majority business model → territorial rootedness → differentiation →*	R	1
	613	0	*territorial rootedness → price of wine → profits → production → quality → categorization on the market → importance of volume in the majority business model →*	R	1
	614	0	*territorial rootedness → differentiation → price of wine → profits → production → quality → categorization on the market → importance of volume in the majority business model →*	R	2
8	801	0	*production → artificial inputs → production costs → production*	B	1
	802	0	*vineyard size → growth target →*	R	0
9	901	1	*profits → profit sharing → mutual trust with producers →*	R	0
	902	1	*purchase of grapes from associated producers → marketing for the company → estimated marketing capacity →*	R	0
	903	0	*profits → profit sharing → mutual trust with producers → costs →*	B	1
	904	0	*profits → profit sharing → mutual trust with producers → grape producers related to each other → purchase of grapes from other producers →*	B	1
	905	0	*profit sharing → mutual trust with producers → grape producers related to each other → purchase of grapes from other producers →*	R	2
	906	0	*mutual trust with producers → grape producers related to each other → purchase of grapes from other producers →*	R	2
	907	0	*investment in winemaking capacity → storage capacity →*	B	0
	908	0	*investment in winemaking capacity → storage capacity → vinification for own vineyard →*	R	1
	909	0	*investment in marketing skills → marketability →*	B	0
	910	0	*opportunity to sell wine to other vineyards → sales of wine to other vineyards →*	R	1

It turns out that each of the variables contained in one or several loops belongs to the set of 219 variables in the aggregated MMDSs. This means that each of them is relevant because it is mentioned in a sufficient number of MMDS and/or because many causal links or paths originate in it. Of course, these variables are not all equally relevant. Also, the number of MMDS where they belong to loops, as well as the number o loops they are contained in show some variation.

The following Table 6 shows these variables, ordered by (1) the number of feedback loops they belong to, (2) their degree of relevance in terms of MMDSs and links or paths. For the sake of displaying the table in a single page, the column names have been abbreviated: M = number of MMDS including the variable; LP = number of causal links or paths originating in this variable; FL = Number of feedback loops containing the variable; R = number of the loops which have been recognized; MMDSs = Number of MMDS containing these loops; MMDS IDs = where the loops appear; G1 = some loops are in MMDS of Group 1; G2 = some loops are in MMDS of Group 2.

Table 6:The most relevant variables are contained in dark loops

Variable	M	LP	FL	R	MMDS	MMDS IDs	G1	G2
quality	3	3	17	1	2	4, 6		1
price of wine	9	12	17	2	3	2, 4, 6		1
production	5	10	13	2	4	2, 4, 6, 8		1
profits	6	5	12	2	2	6, 9		1
profitability	3	3	9	2	2	4, 6		1
costs	8	9	9	0	3	4, 5, 9	1	1
categorization on the market	1	4	7	0	1	6		1
importance of volume in the majority business model	4	9	7	0	1	6		1
sales	6	9	7	0	2	3, 4	1	1
production costs	8	4	6	0	3	4, 6, 8		1
mutual trust with producers	1	3	5	1	1	9		1
personnel costs	3	4	5	0	1	4		1
profit sharing	1	1	4	1	1	9		1
distributors	3	3	4	0	2	1, 3	1	
liquidity	2	4	4	0	1	3	1	
grape producers related to each other	1	1	3	0	1	9		1
frauds	2	3	3	0	1	6		1
purchase of grapes from other producers	2	4	3	0	1	9		1
revenues	5	4	3	2	1	4		1
territorial rootedness	3	6	3	0	1	6		1
differentiation	5	8	3	0	2	2, 6		1
price of grape	5	8	3	0	2	3, 6	1	1
shortage	1	1	2	0	1	2		1
total debt with producers	1	1	2	0	1	3	1	
investment in winemaking capacity	3	4	2	0	1	9		1
storage capacity	1	4	2	0	1	9		1
mechanization	3	7	2	0	1	4		1
demand for wine	5	9	2	0	1	2		1
debt with third parties	1	1	1	0	1	3	1	
growth target	1	1	1	0	1	8		1
marketability	1	1	1	0	1	9		1
sales of wine to other vineyards	1	1	1	0	1	9		1
degree of adjustment of company size	3	2	1	0	1	1	1	
energy costs	4	2	1	0	1	4		1
estimated marketing capacity	1	2	1	1	1	9		1
marketing costs	5	2	1	0	1	4		1
purchase of grapes from associated producers	1	2	1	1	1	9		1
artificial inputs	2	3	1	0	1	8		1

growth rate of big vineyards	1	3	1	0	1	5	1	
investment in marketing skills	1	3	1	0	1	9		1
market power of large vineyards	4	3	1	0	1	5	1	
marketing for the company	1	3	1	1	1	9		1
opportunity to sell wine to other vineyards	1	3	1	0	1	9		1
vinification for own vineyard	1	3	1	0	1	9		1
marketing efforts abroad	1	4	1	0	1	5	1	
innovation	3	7	1	0	1	2		1
vineyard size	3	12	1	0	1	8		1

Visual inspection of Table 6 reveals that where the number of feedback loops (FL) is high, the number of links or paths (LP) is high, too: the more links or paths originate in a variable, the more feedback loops it is contained in. This relationship is shown in Figure 1:

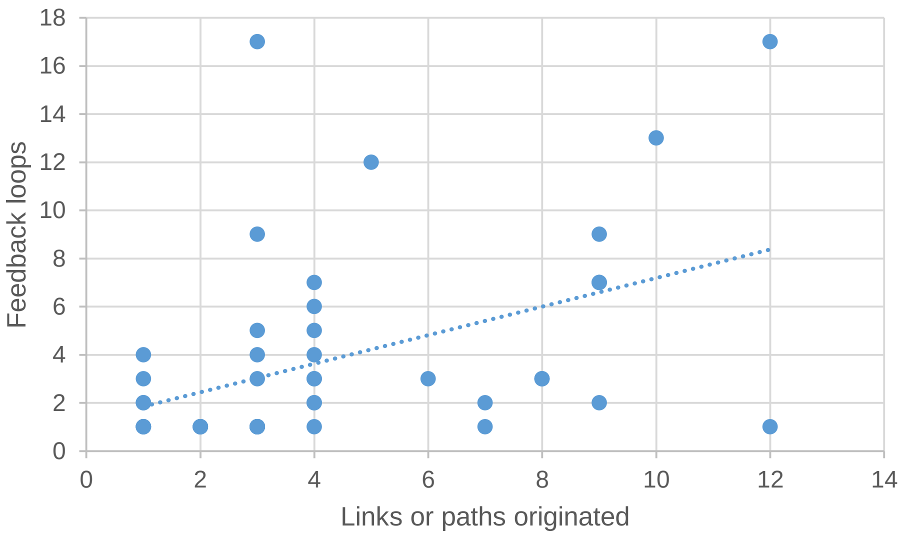


Figure 1: The relationship between the number of links or paths of a variable and the number of loops it is contained in is positive

Given the observation that only 5 out of the 50 feedback loops have been recognized by the interviewed executives (see Table 5), this allows the following proposition:

> **Most of the relevant variables are influenced by multiple 'dark' loops, and the MMDS owner did not recognize this.**

Keeping in mind that the MMDSs of group 1 (G1) tend to consider the *price of wine* as driven by factors they cannot govern, whereas group 2 MMDSs tend to believe the *price of wine* can be influenced by internal decisions, it is also interesting to observe the columns G1 and G2. It turns out that only 8 variables are contained in loops belonging exclusively to G1 MMDSs, whereas 36 are affected by loops only contained in MMDSs of G2 (and 5 belong to both groups). Only the case of *distributors* affects more than one single MMDS (two MMDS out of the three which contain the variable). In comparison, the *price of wine* belongs to each of the 9 MMDSs – so each of the interviewees in each of the groups referred to it - but the 17 loops it is contained in belong to 3 MMDS from G2. This reinforces the observation that G1 executives did not see the a reasonable chance to influence the *price of wine*, but the G2 executives do – even if they did not recognize the circular nature of their corresponding arguments. Another very relevant variable – *costs* – belongs to 8 MMDS, but its 9 loops belong to both groups.

Consider the following two sets of loops shown in Table 7, which either contain the *price of wine*, the *costs* or both. Only 2 of the 17 loops containing the *price of wine* have been recognized, and all 9 lops containing *costs* have remained dark (unrecognized). Both variables are printed fat to make them more salient:

Table 7: Loops containing *price of wine* and loops containing *costs*

Rec	Variables	Pol	Del	*Price*	*Costs*
0	***price of wine*** → *innovation* → *differentiation* →	B	0	1	
1	***price of wine*** → *revenues* → *profitability* → *quality* →	R	0	1	
1	***price of wine*** → *revenues* → *profitability* → *production* → *quality* →	R	0	1	
0	***price of wine*** → *production* →	B	0	1	
0	***price of wine*** → *sales* → *revenues* → *profitability* → *quality* →	B	0	1	
0	***price of wine*** → *sales* → ***costs*** → *profitability* → *quality* → *price of wine*	R	0	1	1
0	***price of wine*** → *sales* → *marketing costs* → ***costs*** → *profitability* → *quality* →	R	0	1	1
0	***price of wine*** → ***costs*** → *profitability* → *quality* → *price of wine*	B	0	1	1
0	***price of wine*** → *personnel costs* → *production costs* → ***costs*** → *profitability* → *quality* →	R	1	1	1
0	***price of wine*** → *personnel costs* → *mechanization* → *production* →	R	1	1	
0	***price of wine*** → *sales* → *personnel costs* → *production costs* → ***costs*** → *profitability* → *quality* →	B	1	1	1
0	***costs*** → *energy costs* → *production costs* →	B	1		1
0	***costs*** → *personnel costs* → *production costs* →	B	1		1
0	***costs*** → *marketing efforts abroad* →	B	0		1
0	*profits* → *price of grape* → *quality* → ***price of wine*** →	R	0	1	
0	*profits* → *production* → *quality* → ***price of wine*** →	R	0	1	
0	*profits* → *frauds* → *quality* → ***price of wine*** →	R	0	1	
0	*profits* → *frauds* → *production* → *quality* → ***price of wine*** → *profits*	R	0	1	
0	*territorial rootedness* → ***price of wine*** → *profits* → *production* → *quality* → *categorization on the market* → *importance of volume in the majority business model* →	R	1	1	
0	*territorial rootedness* → *differentiation* → ***price of wine*** → *profits* → *production* → *quality* → *categorization on the market* →	R	2	1	
0	*profits* → *profit sharing* → *mutual trust with producers* → ***costs*** →	B	1		1

Costs is a variable under the influence of 9 unrecognized lops: while the MMDS owners reason about *costs* in an input-output manner, any change they manage to achieve in *costs* will be fed back and have future consequences they apparently do not consider. In other words, some of the *costs* behavior may surprise them because it has been unintendedly caused by past decisions. In a very similar way, the same holds for *production costs*, *personnel costs*, *marketing costs*, *production*, *sales*, *demand for wine* and *profits* - to mention only the most shared ones (refer to Table 5 and Table 6).

For the MMDS of G1, the *price of wine* is under external influence and therefore one may agree that in such cases, the MMDS display an input-output architecture without loops. However, in the MMDSs of G2, changes in the *price of wine* will trigger 15 unrecognized loops, while the vineyard executives (of G2) expect the *price of wine* to be to be open to discretionary management measures: this is again input-output reasoning, but this time in the presence of as many as 15 more feedback loops than what has been recognized by the executives.

But the problem of not seeing dark loops is not limited to isolated variables. As Table 7 reveals, the *price of wine* and *costs* are connected to one another by feedback loops which contain both variables. To illustrate this, we will analyze the case of the two MMDSs with the greatest number of loops: MMDSs 4 and 6, respectively. Since this analysis focuses exclusively on the loops, all variables which do not belong to the loops are suppressed – even if the belong to the MMDS.

3.2 MMDS4

In a MMDS, variables are simultaneously interconnected by different causal links; the entire model is easier to grasp when represented as a causal loop diagram (M. Schaffernicht 2010; J. Sterman 2000). Figure 2 shows MMDS4 as a tightly interconnected set of variables, in which two loops are specifically labeled because they have been mentioned by the interviewee (the respective causal links are highlighted to make these loops more salient). Links appear as solid arrows, and paths as dotted arrows:

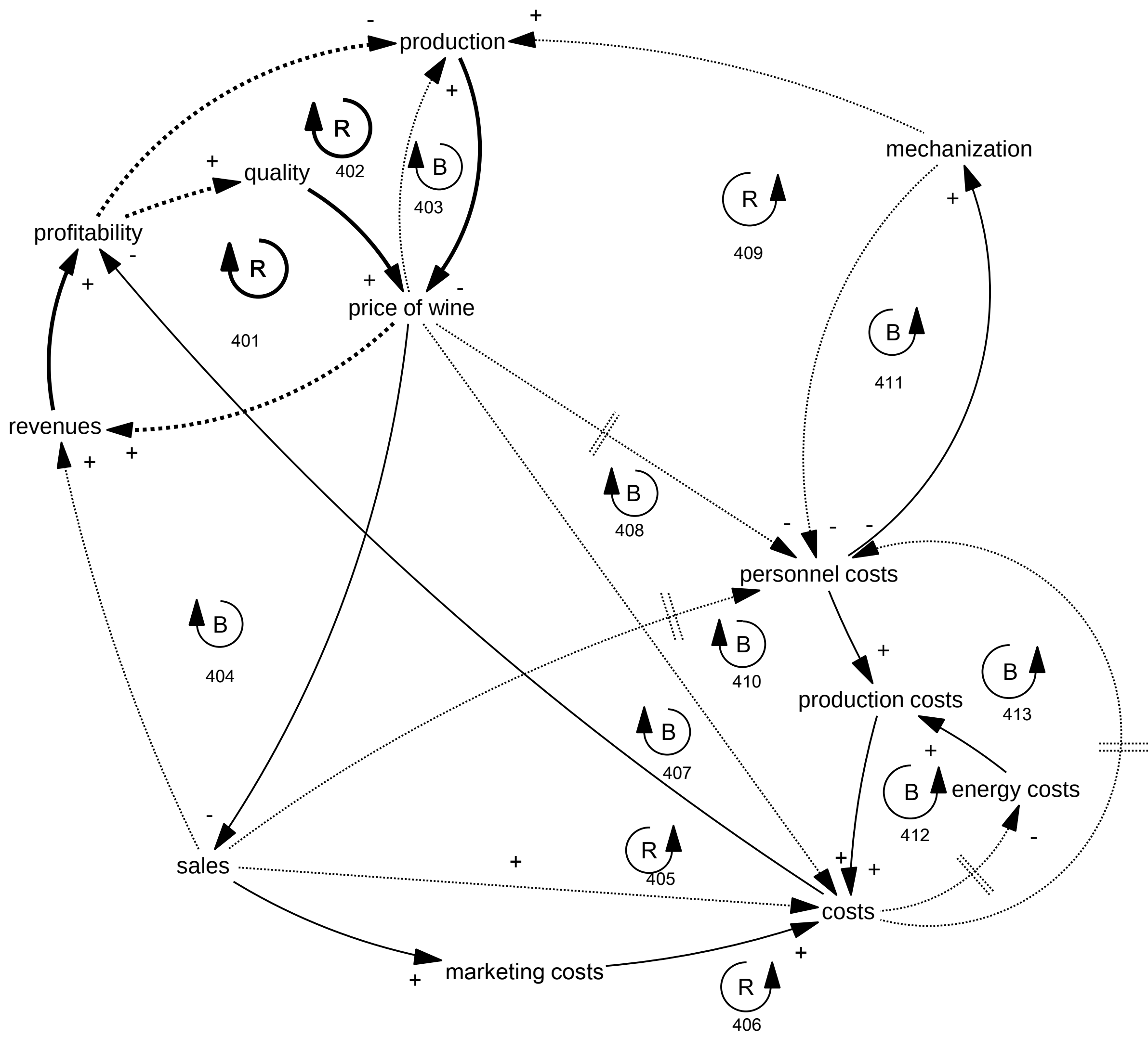


Figure 2: Causal map of MMDS4 with recognized and ‘dark’ loops

Figure 2 allows to see the whole set of loops, but also to examine each loop separately. The very nature of loops has it that there is no beginning and no end; however, selecting a variable at the crossing of several loops is a good heuristic to start somewhere. In the case of MMDS4, many loops contain the *price of wine*. Loop 401 describes how an **increase** of the *price of wine* **increases** the vineyard's *revenues* (note that this is a path, which in the original MMDS4 passes through *revenues from wine sales*) and subsequently **increases** *profitability*. This allows them to **decrease** *production* over another path (reducing their grape *production per hectare*); when there are **less** grapes per hectare, the *quality* of the resulting wine **increases** and consequently there arises a pressure to **increase** the *price of wine*. Thus any **increase** of the *price of wine* will lead to a further **increase** of the *price of wine*: this loop is reinforcing – its causal structure will reinforce an initial change will lead to another change with the same sign.

In loop 402, the same **increase** in *profitability* will (also **decrease** *production per hectare* and therefore) lead to a **reduced** *production*, which will – all other things equal – lead to an **increased** *price of wine*. This is a reinforcing loop, too. Note that by the same token, any **decrease** of the *price of wine* will lead to pressures towards **increasing** the *price of wine*: just like Janus hat two faces, reinforcing loops have two operational modes: virtuous or vicious.

The remaining variables and causal links have been mentioned by the interviewees without explicitly connecting it to these two loops are recognizing how they build a house set of other feedback loops. Figure 2 has been laid out in a way which facilitates visual recognition of loops; note that the interviewee does not receive such visual feedback during the interview. However salient these cyclical visual arrangements may be, some of these loops are quite long and partially overlap with other loops. The list of variables per loop was shown in Table 5 (above).

Loop 403 also has to do with the *price of wine*: when it **increases**, there will be an **increase** in *production* (because **increased** *incentives to grow grapes* lead to an **augmented** *planted area*), which in turn will **decrease** the *price of wine*. Thus any **increase** of the *price of wine* will lead to a subsequent **decrease** of the *price of wine*. Since the sign of the initial change is inverted, this is a negative or "balancing feedback" loop (labeled with a "B"), expressing the fact that in the (social) system, there is a process whose influence on the *price of wine* limits the decision maker's ability to influence the *price of wine*. Loop 404 adds the inverse relationship between *price of wine* and *sales* as a balancing loop. Loops 405 and 406 articulate the observation that selling costs money and therefore *sales* **increase** *costs*, yielding two very similar balancing loops (405 including a longer path, 406 mentioning *marketing costs* explicitly). Loops 407 and 408 state that a higher *price of wine* indirectly (path) leads to **increased** costs, and that a **higher** *price of wine* leads to **increased** *personnel costs*, too. Both loop state a **decrease** of *profitability* with the ensuing **decrease** of the *price of wine*: balancing loops. Loops 409 and 411 cycle around the **increase** of *mechanization* in order to **decrease** *personnel costs* (411 is a balancing loop), which at the same time *increases* **production** because of increased productivity (409 is reinforcing). Loop 410 is balancing and describes that an **increase** in *personnel costs* **resulting** from an **increased** *price of wine* **increases costs** which **reduces** *profitability* and leads to a **decrease** of the *price of wine*. Eventually, loops 412 and 413 are balancing and describe how *energy costs* and *personnel costs* are being controlled.

It is relevant to note that the first four loops (401 – 404) focus mainly on the *price of wine*, loops 405 – 411 deal with the *price of wine* and with *costs*, and loops 411 – 413 concentrate on *costs*.

3.3 MMDS6

In the case of the second MMDS, there is one recognized loop. Loop 601 is balancing and represents the inverse relationship between the *profits* and *production*. Loop 602 counters this with the observation that **increased** *profits* **increase** *profitability* and attract **additional** *production*. 603 adds that increasing production also increases production costs, diminishing profits. Loop 604 states that **increased** *profits* tend to **increase** the *price of grape*, which leads to an **increase** in the *quality* (of the resulting wine) and **increases** the *price of wine*, thereby further **increasing** *profits*. Recall that the same loop will also reinforce a possible **decrease** of the *price of wine*. Loop 605 articulates the reaction of *quality* to changes in *production*: **increasing** the *production* (volume) tends to **decrease** the *quality*, which **decreases** the *price of wine* and **diminishes** *profits*, then leading to a further **increase** in *production*: a reinforcing loop. *Frauds* are introduced in loop 606: a **decrease** in *profits* will **increase** *frauds*, which will **decrease** *quality*, then **diminish** the *price of wine* and finally further **decrease** *profits*: this looks like the vicious side of a reinforcing loop. *Frauds* also tend to **increase** *production*, which connects loop 607 to the same logic which characterizes loop 605.

Loops 608-610 build a delayed connection between *quality* and the *categorization on the market*. An **increased** *quality* slowly **increases** the *categorization*, which **reduces** the *importance of volume in the majority business model*: (sales) volume is less important when you market a highly ranked wine. This leads to a **more generous** *price of grape*, **less** *frauds* and **less** *production* in general. The consequence will be a **higher** *quality*: a threefold reinforcing process. Again, this may as well lead into a spiral of **decreasing** *categorization*! Loops 611-614 describe how the *importance of the volume in the business model* interacts with the *territorial rootedness* (how strongly the vineyard and its people feel connected with their terroir), with *differentiation* and with the *price of wine*; these are reinforcing loops, which can therefore either **decrease** the *importance of the volume* or **increase** it.

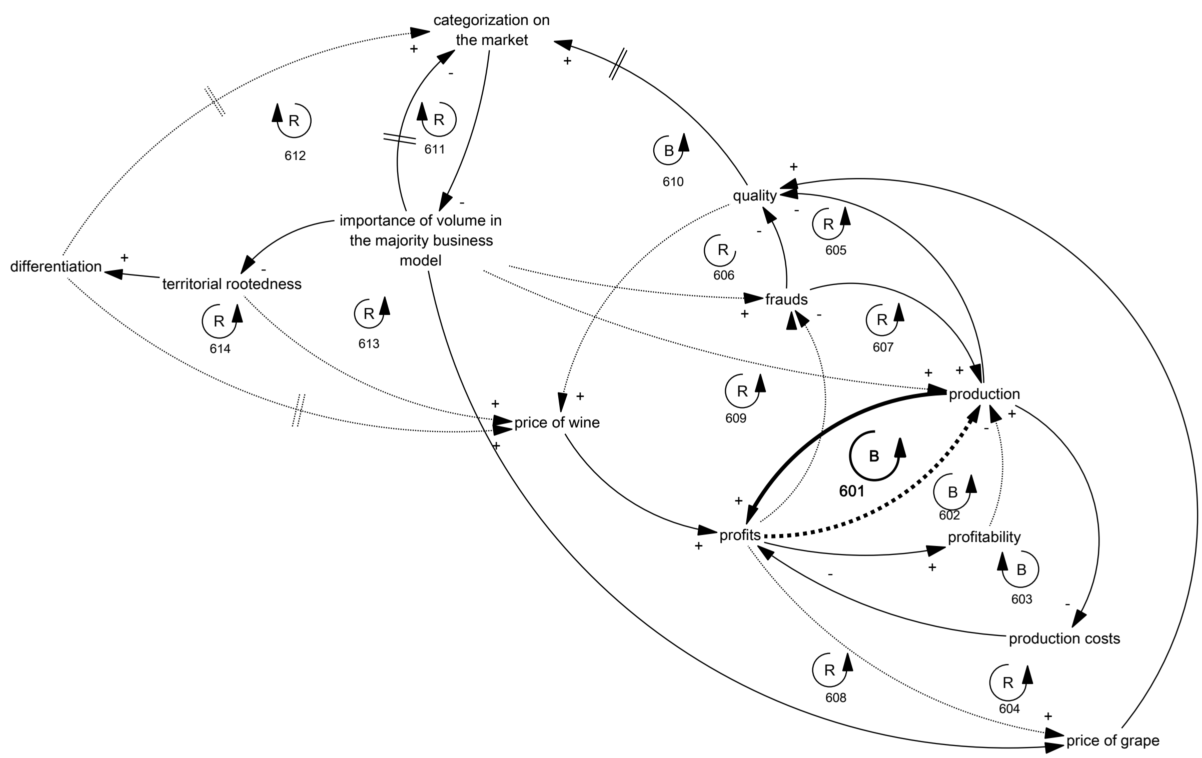


Figure 3: Causal map of MMDS6 with recognized and 'dark' loops

4 Discussion

4.1 The coverage of inherent loops in MMDS4

For single causal links and paths, the ‘ceteris paribus’ condition is usually applied. However, variables like the *price of wine* or *costs* belong to multiple loops (Table 7), some of them reinforcing any change, others balancing changes. So ‘ceteris paribus’ has to be dropped when considering the entire business situation. By not recognizing 8 of the 10 loops directly affecting the price of wine, an executive may think of variables like *personnel costs* or *mechanization* as levers which can be used in an input-output manner. But if a discretionary decision concerning *mechanization* has a ‘side effect’ in the *price of wine*, an individual who believes such a connection does not exist will not recognize the consequences. Even more so, he cannot take into account the consequences of the fact that many loops are interconnected by the *price of wine* and by *costs*, and that it is impossible to influence any of their variables without triggering effects in all loops and their respective variables.

The question arises if all loops in MMDS5 are interconnected or if there are independent groups. Since any intersection between a pair of loops means that they have at least one variable in common, inspection of how the variables intersect across the MMDS allows to answer this question. The following Table 8 contains the variables of MMDS1 and indicates their presence in each of its ten feedback loops. The 5 variables in the upper section of the table belong to the loops recognized by the interviewee (loops 1 and 2), while the 7 variables in the lower section do not belong to any recognized loop.

Table 8: Presence of variables in feedback loops, MMDS4

Variables	**Loops**												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
profitability	1	1		1	1	1	1	1		1			
price of wine	1	1	1	1	1	1	1	1	1	1			
production		1	1						1				
quality	1	1		1	1	1	1	1		1			
revenues	1	1		1									
costs					1	1	1	1		1		1	1
energy costs												1	
marketing costs						1							
mechanization											1		
personnel costs								1	1	1	1		1
production costs								1		1		1	1
sales				1	1	1				1			

Inspection of the upper part of Table 8 reveals that loops 1 through 10 heavily intersect: the *price of wine* belongs to each of these loops, and each of the other variables is either in loops 1, 2 and 4-10 or in loops 2, 3 and 9. Loops 4 - 10 also have variables in the lower section of the table – these variables have been mentioned by the interviewee, but the loops they belong to have not been recognized. These variables, in turn, belong to the loops 4 through 10. This means that if something is changed in a variable belonging to one of the loops 1 or 2 – which have been recognized by the interviewee, the price of wine will be influenced; this will also trigger the loops 3 through 10, which will then also trigger loops 11 through 14.

The connections between the loops can be represented as an adjacency matrix, where there is a row and a column for each loop. If there is a connection from the loop in row *r* to the loop in column *c*, then the $\text{cell}_{r,c}$ is set to 1 (blank or cero otherwise). Each pair of 1 in Table 8 is such a connection; for instance, the first row (variable *global supply*) connects loops 1, 4, 5 and 6 to one another. Table 9 shows the adjacency matrix for the loops in MMDS1 in the left section (zeros have been replaced by blanks for visibility):

Table 9: Adjacency and distance matrices for the loops in MMDS4

Adjacency matrix of the loops in MMDS 4

Loop	1	2	3	4	5	6	7	8	9	10	11	12	13
1		1	1	1	1	1	1	1	1	1			
2	1		1	1	1	1	1	1	1	1			
3	1	1		1	1	1	1	1	1	1			
4	1	1	1		1	1	1	1	1	1			
5	1	1	1	1		1	1	1	1	1			
6	1	1	1	1	1		1	1	1	1			
7	1	1	1	1	1	1		1	1	1			
8	1	1	1	1	1	1	1		1	1	1		1
9	1	1	1	1	1	1	1	1		1	1		1
10	1	1	1	1	1	1	1	1	1				
11								1	1	1		1	
12					1	1	1	1		1			1
13					1	1	1	1		1		1	

Distance matrix of the loops in MMDS 4

Loop	1	2	3	4	5	6	7	8	9	10	11	12	13
1		1	1	1	1	1	1	1	1	1	2	2	3
2	1		1	1	1	1	1	1	1	1	2	2	3
3	1	1		1	2	1	1	1	1	1	2	2	3
4	1	1	1		1	1	1	1	1	1	2	2	3
5	1	1	1	1		1	1	1	1	1	2	2	3
6	1	1	1	1	1		1	1	1	1	2	2	3
7	1	1	1	1	1	1		1	1	1	2	2	3
8	1	1	1	1	1	1	1		1	1	1	1	2
9	1	1	1	1	1	1	1	1		1	1	1	2
10	1	2	1	1	1	1	1	1	1		2	2	3
11	2	2	2	2	2	2	2	1	1	1		2	1
12	2	2	2	2	1	1	1	1	2	1	2		1
13	2	2	2	2	1	1	1	1	2	1	2	1	

Visual inspection of the adjacency matrix suggests that the loops 1 through 10 are massively interconnected, and that the connections are lose between loops 11 through 14. There is no direct connection from the loops 1 – 7 to any of the loops 8-13. However, the adjacency matrix contains only 0 and 1, representing only the direct connections between the loops. Loops which are more than one step away, can be made visible in a distance matrix; such a matrix has the same structure as the adjacency matrix, but its cells contain the number of steps to reach the loop represented in column *c* from the loop represented in row *r*. To construct the distance matrix, one can directly use the data in the adjacency matrix. For example, $cell_{1,11}$ in the adjacency matrix is equal to zero: there is no direct connection from loop 1 to loop 11. But $cell_{1,8}$ in the adjacency matrix is equal to 1; therefore inspect row 8 (loop 8), column 11, which is equal to 1. This means that in 2 steps, one can reach loop 11 starting at loop 1, and therefore the $cell_{1,11}$ in the distance matrix receives a 2. The distance matrix of the loops in MMDS (right section in Table 9) clearly reveals that all loops of MMDS can be connected in 1, 2 or 3 steps. This means that any change to any variable in any loop will affect all variables of all loops.

4.2 The coverage of inherent loops in MMDS6

Analogously, most of the variables in MMDS6 belong to more than one feedback loop, as shown in Table 10. Similarly to MMDS4, the upper block contains the 2 variables which belong to the two recognized loops, whereas the 10 variables belonging to unrecognized loops are in the lower block. The upper block variables are mainly part of the loops 1 – 9 and 13-14, but only loops 10-12 are not directly connected to these loops. However, each of the variables in the lower part of the Table also connects with either one of the two recognized lops, or with another lower part low which in turn has such a connection.

Table 10: Presence of variables in feedback loops, MMDS6

Variables	**Loops**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
production	1	1	1		1		1		1				1	1
profits	1	1	1	1	1	1	1						1	1
categorization on the market								1	1	1	1	1	1	1
profitability		1												
differentiation												1		
frauds										1				
importance of volume in the majority business model								1	1	1	1	1	1	1
price of grape				1				1						
price of wine				1	1	1	1						1	1
production costs			1											
quality				1	1	1	1						1	1
territorial rootedness												1		1

The adjacency matrix of the loops of MMDS6 shown in

Table 11 suggests that there are two groups of loops: 1 – 9 and 10 – 14 are tightly interconnected amongst one another, but with little connection between the groups. However, the distance matrix reveals that the loops of these two groups are no further than 2 steps apart from one another. Just like in the case of MMDS4, the second interviewee did recognize only a small minority of the loops inherent in the structure of the variables and causal links he articulated during the interview.

Table 11: Adjacency and distance matrices for the loops in MMDS

Adjacency matrix of the loops in MMDS 6

Loop	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1		1	1	1	1	1	1		1				1	1
2	1		1	1	1	1	1		1				1	1
3	1	1		1	1	1	1		1				1	1
4	1	1	1		1	1	1						1	1
5	1	1	1	1		1	1		1				1	1
6	1	1	1	1	1		1		1					
7	1	1	1	1	1	1		1					1	1
8				1					1	1	1	1	1	1
9	1	1	1		1		1	1		1	1	1	1	1
10								1	1		1	1	1	1
11								1	1	1		1	1	1
12								1	1	1	1		1	1
13	1	1	1	1	1	1	1	1	1	1	1	1		1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	

Distance matrix of the loops in MMDS 6

Loop	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1		1	1	1	1	1	1	1	1	1	2	2	2	2
2	1		1	1	1	1	1	1	1	1	2	2	2	2
3	1	1		1	2	1	1	1	1	1	2	2	2	2
4	1	1	1		1	1	1	2	1	1	2	2	2	2
5	1	1	1	1		1	1	1	1	1	2	2	2	2
6	1	1	1	1	1		1	1	2	2	2	2	2	3
7	1	1	1	1	1	1		1	1	1	1	2	2	2
8	1	1	1	2	1	1	1		1	1	1	1	1	2
9	1	1	1	1	1	1	1	1		2	1	1	2	1
10	1	1	1	1	1	1	1	1	1		1	1	1	1
11	2	2	2	1	2	2	2	1	1	1		1	1	2
12	2	2	2	2	2	2	2	1	1	1	1		1	1
13	2	2	2	2	2	2	2	1	1	1	1	1		1
14	2	2	2	2	2	2	2	1	1	1	1	1	1	

4.3 The consequences of not recognizing dark feedback loops

Each of the executives recognized that the variables belonging to the recognized loops are driven by these loops, as virtuous cycles or as vicious cycles. Variables not belonging to any of the recognized loops could then be influenced in a one-off manner. For instance, the first executive could decide to **increase** *mechanization* to **increase** *labor efficiency* (this intermediate step is aggregated in the path shown in Figure 2 and Figure 4), thereby **reducing** the *personnel costs* to **reduce** the *production costs* and **diminish** *costs*. There is a manifest difference between thinking to **increase** *mechanization* in order to **reduce** *costs* and **increase** *profitability*, like displayed in Figure 4, and keeping in mind that a change to *mechanization* will trigger all loops shown in Figure 2 and set off cyclical changes in all variables.

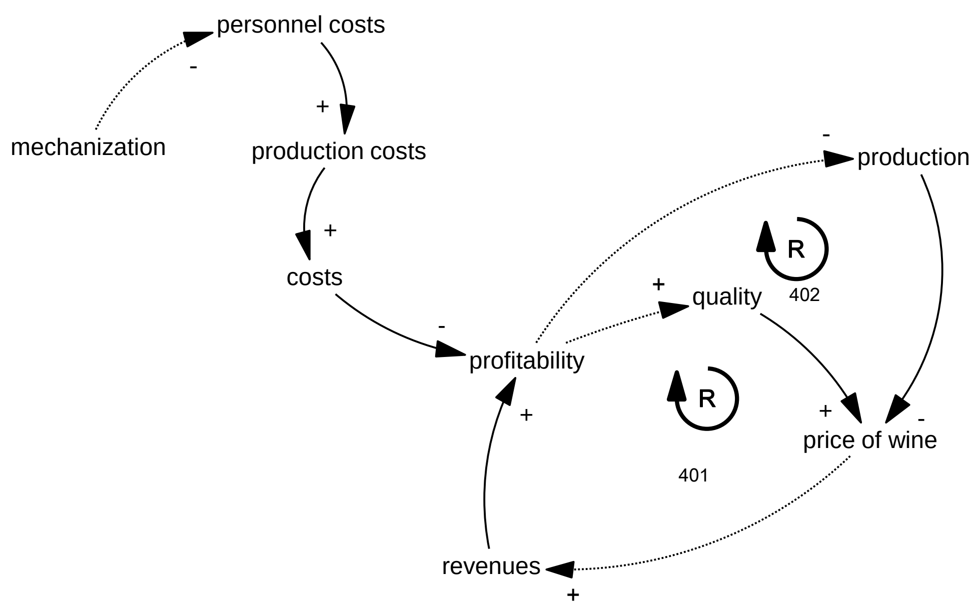


Figure 4: Causal diagram of a plan to **increase** *profitability*

Analogous reasoning could be made with *costs, energy costs, marketing costs, mechanization, personnel costs, production costs, sales* (MMDS4) and *categorization on the market, profitability, differentiation, frauds, importance of volume in the majority business model, price of grape, price of wine, production costs, quality, territorial rootedness* (MMDS6). Considering that out of the dark loops, 3 and 11 respectively are reinforcing in nature, instability may be caused without the ability to recognized its endogenous cause. Of course, without quantification and simulation, it is not possible to know how important the combined effects of these dark loops will be in each case.

This limitation notwithstanding, any change to one of the variables in MMDS4 or MMDS6 will not only have several side effects, but also come back to the initial variable in several ways. One single decision will trigger sequences of behavior change, rather than one single event. Taking these variables as possible levers for management decisions in an input-output way of reasoning will not be able to take this into account. Mental models are the structure used to reason through different possible decisions (Johnson-Laird 2001), but if the structure of the mental model is only partially recognized and understood, then many decisions may be derived rather by repeating decisions from past experience than from systematically analyzing the given possibilities.

Summing up, the interviewees behind MMDS4 and MMDS6 recognized only 20% and 13% of the inherent loops in their MMDS, respectively. This made 57% and 77% of the variables mistakenly seem to be free of the influence of feedback loops. The analysis of the two exemplary MMDSs makes a strong case for the proposition that

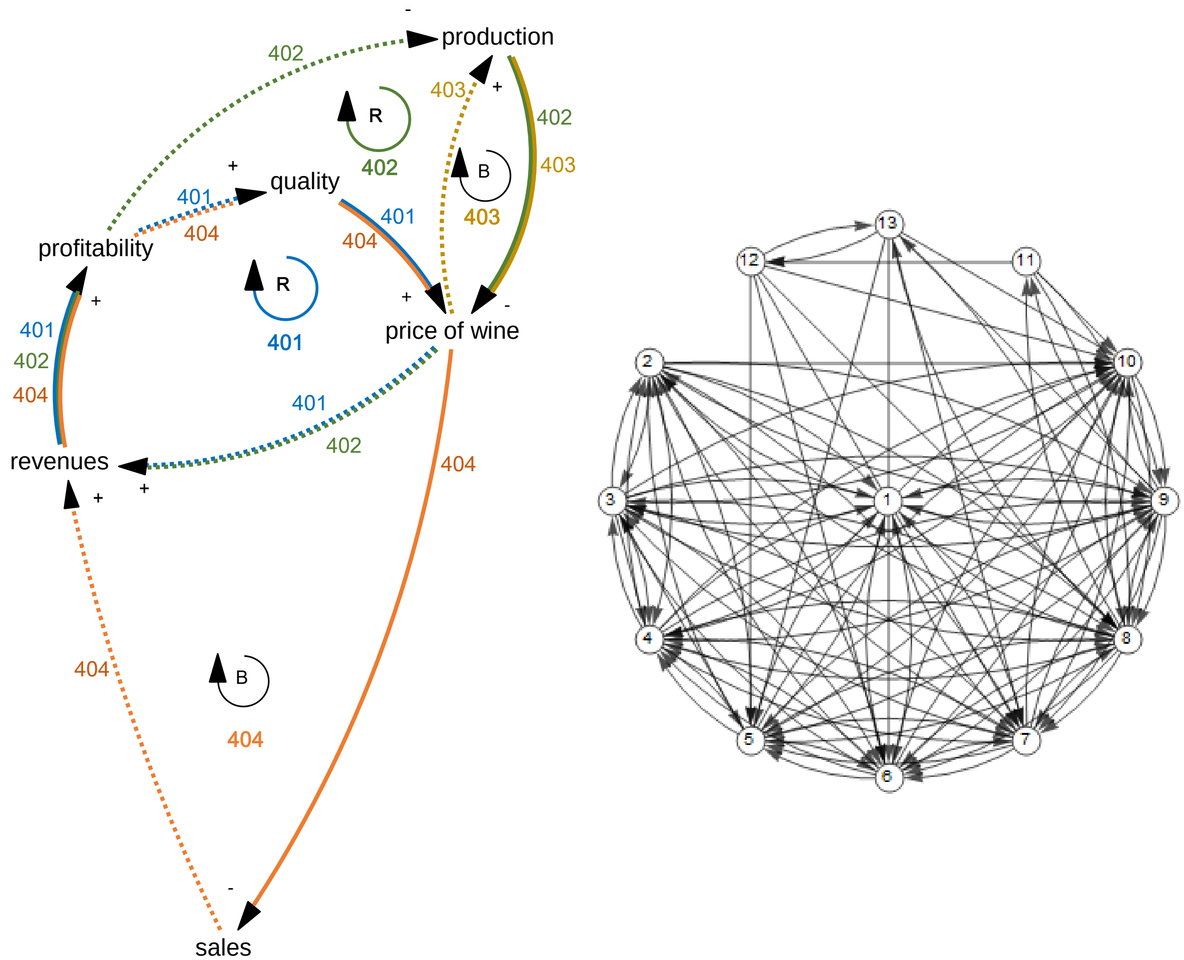
Untrained decision-makers and planners need assistance to recognize dark loops.

This is not diminished by the observation that the remaining MMDS have less dark loops – even that one of the MMDS did not have any such loop at all. The fact remains that in almost all of the MMDSs, the majority of the relevant variables was contained in dark loops.

4.4 Challenges for research

Therefore there is a need for tools helping executives to recognized what their mental models contain. It is inherently helpful to use an external "boundary object" (Black 2013). The "cognitive mapping" thread has contributed some tools (Eden 2004), but these are input-output oriented and do not help to recognize feedback loops. System dynamics is based upon feedback loops (Forrester 1969; J. Sterman 2000), but its tools are aimed at simulation modelling and demand too much training to be a tool for executives. Qualitative modeling of feedback-rich situations is prone to misinterpreting behavioral consequences (M. Schaffernicht 2010); however, not being able to determine plausible behaviors from a qualitative causal loop diagram is preferable to not even recognizing the loops in the first place. Clearly, a tool able to automatically detect feedback loops and classify their polarity while a executive or a management team work through a problem – identifying variables and causal links – would give executives the opportunity to more thoroughly consider possible strategies, decision policies or plans.

While the main software tools for system dynamics diagramming and modeling include a feature which detects if a given variable belongs to loos (and which ones), this function has to be invoked by the modeler each time, it refers only to the selected variable(s) and it is presented as pop-up information which becomes invisible as soon as the modeler clicks on the diagraming canvas. This is not a trivial user interface problem to solve because not only are there multiple loops, but on top of it most causal links participate in several loops at the same time. One way to feed this information graphically back to the user/modeler can be to define a separate color for each loop and draw each link one per loop, with its respective color. Additionally, the ID of each loop can be displayed along the causal links. It may even become useful to create a new kind of diagram, where the loops are represented as nodes in a network (or a directed graph), and arrows showing the connections between them. Figure 5 shows how this might look in the case of the first 4 loops in MMDS 4, and how interconnected the network of loops of MMDS 4 is.



a) Causal diagram showing loops (part of MMDS 4). Dotted arrows are paths. Color indicates loop ID.

b) Network diagram of the loops in MMDS 4. Nodes represent loops. Arrows represent connections because of shared variables.

Figure 5: Options for assisting decision makers and modelers

One challenge for the programs running beneath the user interface would be the automatic detection of loops including the recalculation of the shortest independent loop-set. This may be rendered even more difficult if the user/modeler wishes to rearrange the loop set because his business logic and his mental model do not strictly comply to the rules and conditions of a shortest independent loop set.

This is certainly a challenge for software developers, but such a tool would doubtlessly be of substantial help for planners, decision makers and consultants.

There is also a need for tools supporting researchers investigating the mental models of executives and other decision makers. The need for taking feedback loops into account has been argued for (S. N. Groesser and M. F. Schaffernicht 2012) and the so-called ‘distance ratio’ method (Markóczy and Goldberg 1995b) has been adapted (M. F. Schaffernicht and S. N. Groesser 2011), but the current tools (M. F. Schaffernicht and S. N. Groesser 2014) only take into account the feedback loops recognized by the interviewees. The “loop distance ratio” (LDR) compares the elements (variables and causal links), the polarity and the delays of those loops which the interviewees have recognized and the researchers deem to be equivalent. For instance, neither of the two recognized loops in MMDS4 is equivalent to any of the recognized loops in MMDS6, and therefore the LDR would be 100% (maximum distance, in other words: completely different MMDS). However, amongst the unrecognized loops, there are equivalences, like displayed in Table 12:

Table 12: Equivalent loops

MMDS	Loop	Pol	Del	Elements
4	402	R	0	*price of wine → revenues from wine sales → revenues → profitability → production →*
6	602	R	0	*profits → profitability → production →*
4	412	B	1	*energy costs → production costs → energy efficiency →*
6	603	B	0	*profits → incentive to decrease costs → production volume → costs*

A third challenge refers to MMDS elicitation. As opposed to intervention and consulting, research projects usually take great care to avoid or minimize the influence of the researcher on the participating individuals. This has lead to the interview – transcribe – code procedure applied in the current study. It also meant that no visual feedback was given to the interviewee during the interview. However, this lead to the researcher making multiple choices regarding causal links and can have some undesired consequences. The interviewee may not mention a variable or a causal link or even a loop which is completely obvious to him, leading to the danger that “not mentioned” is mistakenly interpreted as “not recognized”; it is then up to the researcher to prompt for sufficient elaboration on behalf of the interviewee without priming or directing him. The fact of constructing and displaying the causal loop diagram (like the ones shown in Figure 2 and Figure 3) during the interview would allow the interviewee to articulate that which was obvious to him (but maybe not to the researcher). As far as mental model research is carried out with experienced executives as participants, the danger that the diagram might influence the interviewee’s mental model is minimal. A diagramming tool like the one described above would be highly useful to assure that the interviewee articulates every variable, link and loop he internally recognizes.

5 Conclusions

This paper had the purpose to show that in matters of mental model comparison, there is a significant difference between those loops which individuals recognize when they talk about the subject and those loops which are inherent in the structure they articulate but which remain dark. Out of nine executives interviewed in the study reported here, only three recognized any feedback loops at all: 45 of the 50 loops have remained dark and unrecognized, implying that the 47 most relevant variables in this set of MMDS are held to be part of input-output models by the executives, but are really endogenously driven by manifold feedback loops.

By consequence, an important share of each model’s variables had not been recognized as being under the influence of loops. It has also been shown that by taking into account only recognized loops, current methods and tools for mental model comparison may provide biased quantifications of how similar or distant a pair of mental models is at the level of loops.

The mental model findings support the statement that without an external support, the mental models of executives will be incomplete and the executives’ assessment of possible strategies and policies will not be based on a thorough analysis of the likely unfolding of their management situations.

Based on this, a call is made to develop tools which help decision makers articulate variables and links and which automatically detect and display loops, so that they be dark loop no longer. Such tools will also be helpful for mental model researchers. There is also a need to adapt mental model comparison methods and tools at the level of loops, helping to quantify the impact of the differences between the recognized and the inherent loops.

Specifically for mental model research, the method and the tools for MMDS analysis and comparison (M. Schaffernicht and S. Groesser 2014) will be enhanced by incorporating the possibility to detect and utilize the SILS, make intra-model comparisons based on the different loop set and calculate two sets of ‘loop distance ratios’ based on the recognized feedback loops and the SILS. This will allow to quantify the distance between the mental model articulated by the decision maker and the mental model which an analyst with experience in system dynamics hordes of the decision-makers mental model.

Of course, a study based on as few as nine mental models is limited by the small sample size. This limitation notwithstanding, under the current conditions the effort to interview, code and analyze is huge and may be prohibitive for many researchers. Therefore hope is that the availability of the methods and tools called for would make mental model research less time consuming and more attractive.

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