ARTICLE IN PRESS

Futures xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

Coping with complexity: Variety regulation by honey bee nectar foragers

Richard Anthony Foss[a,*], Raul Espejo[b]

[a] Natural Systems Development, Aylsham, UK
[b] Syncho Research, Lincoln, UK

ARTICLE INFO

Keywords:
Complexity management
Variety regulation
Interactions
Bee colony

ABSTRACT

In the age of social networks, and also of an extensive use of Artificial Intelligence, a deeper understanding of the interactions among thousands of individuals should help us in the quest of designing effective procedures to manage the 'bigdata' that is overwhelming our human capacity to deal with increasing complexity. This paper offers insights, grounded in the bee colonies natural evolution, to manage this detailed complexity or variety. Variety balances between the nectar foraging and storage operations of the honey bee colony are important for its growth and survival. If there is an optimal variety balance between foragers and storers, their work capacities will be matched and the two operations will function at maximum efficiency. Foragers sense variety imbalances by observing significant deviations from the normal mean levels of the queuing delay experienced when they unload their nectar to the food storers. If there is a short delay, they perform waggle dances to recruit additional foragers but, if there is a long delay, they perform tremble dances to recruit additional storers. These signals reallocate labour to rebalance the system. In addition, algedonic signals are used to recruit or inhibit workers in emergencies. This study shows how a self-organising system can sense and correct variety imbalances without any metasystemic intervention or design.

1. Introduction

This is the second of two independent but related articles. Its aim is discussing interactions in nature, in particular in a bee colony. In the age of social networks, and also of an extensive use of Artificial Intelligence, a deeper understanding of the interactions among thousands of individuals should help us in the quest of designing effective procedures to manage the 'bigdata' that is overwhelming our human capacity to deal with increasing complexity. This 'futures' aspect of paper offers insights, grounded in the bee colonies natural evolution, to manage this detailed complexity or variety.

Contrary to human organisations, bee colonies have evolved with bottom-up, non-hierarchical relationships. This article contributes towards overcoming some of the shortcomings of human organisations highly driven by top-down structures; it offers a learning story from nature's bottom-up structures. It is a highly science focused research and is the outcome of decades of research of natural systems. The first article (Espejo & Foss, 2018) offered a discussion of interactions in human organisations with the support of the Viable System Model (Beer, 1972, 1979, 1985), the Viplan Method (Espejo & Reyes, 2011) and the findings about interactions and requisite variety of this article. This article had the benefit of the systemic framework offered by Espejo's Viplan methodology which revealed aspects of the boundaries and structures necessary to consider when studying how natural selection had solved the problems

* Corresponding author.
E-mail addresses: richardafoss@outlook.com (R.A. Foss), r.espejo@syncho.org (R. Espejo).

https://doi.org/10.1016/j.futures.2018.07.008
Received 28 February 2018; Received in revised form 17 May 2018; Accepted 13 July 2018

of sensing and correcting imbalances of variety in self-organising situations where there is little or no metasystem to guide, design or engineer the requisite variety balances.

One of the greatest problems faced by a modern day human organisation is how to manage complexity (Beer, 1979; Espejo & Reyes, 2011). Labour, materials, machinery, money, energy and information seem to interact at an ever increasing rate and often threaten to overwhelm the management structures that have emerged to deal with them. In order to understand the problem, complexity needs to be measured and counterbalanced by management and operational capabilities. A most useful measure of complexity is variety which counts the number of possible states of a system (Ashby, 1964; Beer, 1972, 1979; Espejo & Reyes, 2011; Espejo, 1989; Waelchli, 1989).

A large body of work exists which gives us a reasonably good theoretical understanding of Ashby's Law of Requisite Variety (Ashby, 1964) and how variety capacity and balances should be designed within human organisations (Beer, 1972,1979, 1985; Espejo & Reyes, 2011). It has been said that this needs to be translated further into active prescriptions that a manager can use in the rapidly complexifying and more self-organising systems of today (Espejo & Reyes, 2011; Rios, 2012; Schwaninger, 2009; Waelchli, 1989). However, because of new technology and increasing connectedness, the key issue is now becoming how variety balancing can be achieved by guided self-organisation, rather than by prescription.

This paper takes the view that it may help to consider how natural selection has solved some problems of variety management in a biological self-organising social system. It provides a practical example of how the honey bee colony copes with the complexity of its foraging environment. Nectar collection and storage are probably the most complex operations carried out by the colony. They are also the best studied operations and they therefore provide an excellent model system for understanding how self-organising systems cope with complexity (Anderson & Ratnieks, 1999b; Seeley, 1995).

A typical honey bee colony contains a queen, who is the mother of all the bees in the colony, some 20–50,000 workers who are all female, several hundred drones who are all male and seasonally varying amounts of brood in various stages of development. Young adult workers start work as nurses and cleaners looking after the brood in the centre of the hive. As they become older they are physiologically able to undertake jobs further from the centre of the hive, first working as comb builders, then as food storers and finally as foragers collecting nectar, pollen, water and propolis from the field. Colony cohesion is provided by a blend of the queen's pheromones, known as queen substance and this is distributed around the hive by messenger bees (Foss, 1989; Free, 1977; Seeley, 1995).

A healthy honey bee colony can deploy thousands of foragers to monitor some 100 square kilometres of surrounding countryside for suitable flower patches, choose the most profitable patches to work in, track changes in nectar abundance throughout the day, balance its rate of nectar processing in the hive with its rate of nectar collection from the field and ensure adequate comb building for nectar storage (Seeley, 1995; von Frisch, 1967). The colony can do all this while at the same time regulating its pollen collection to match its internal supply:demand ratio. It can also collect sufficient water both to maintain the growth and development of some 20–50,000 members and to cool the hive in warm weather (Kuhnholz & Seeley, 1997). Yet there is no control hierarchy or central planning capability to co-ordinate activities within the colony and no member has a synoptic view of all the colony's operations. Instead, each worker bee is her own informant and chief (Free, 1977), so control or more precisely coordination is highly distributed between thousands of individuals. The bee colony is a wonderful example of the power of self-organisation and what can be achieved with only a rudimentary metasystem.

This, of course, raises interesting questions of how a social system can sense and correct imbalances of variety or work capacities if it is self-organising and there is little or no metasystem to guide, design or engineer the requisite variety balances. The purpose of this study is to reveal how natural selection has solved these problems. Knowledge of the variety regulation mechanisms operating in a highly interconnected, dynamic and self-organising system like the bee colony may help us to understand better the future direction of peer production enterprises, liquid organisations and mass collaboration projects in the human domain (Espejo & Foss, 2018).

2. Results and model

This study of variety regulation by honey bee nectar foragers is based on an extensive review of the last 100 year's published literature about the foraging behaviour of honey bee colonies since Karl von Frisch started his classical work on their dance language in 1914 (von Frisch, 1967). The investigation introduces a new approach to this body of work by utilising a cybernetic model of the nectar collection and storage primary operations to analyse the flows of information, raw materials and labour involved. This model is based on Stafford Beer's Viable System Model, but it has been adapted to focus on how variety is regulated in these two operational units (1979, Beer, 1972). The complete model of the organisation of the honey bee colony has previously been described in earlier work (Foss, 1989).

The nectar collection and storage model is shown in Fig. 1.

The honey bee colony's interactions with flowering plants in the accepted foraging environment of the hive at H, I, P and Q provide the essential context for the colony's viability. In order to understand the bees' interaction networks within the hive, it is necessary to obtain a systemic view of how colonies interact with their environment. Flowering plants produce flowers with nectar and pollen to attract bees and other flower visitors; in return the flower visitors inadvertently transport pollen and effect pollination of flowers of other plants of the same species, fertilising them and producing seeds (Waser & Ollerton, 2006; Willmer, 2011). Interactions between flowering plants and pollinators are generally considered to be mutualistic because both plants and pollinators gain benefits. Most insect pollinators, including the honey bee, are generalists, visiting a range of different flowering plant species and many flowering plant species are also considered generalists, being visited by many different species of insect pollinators. However, fine-tuned adaptations exist which are considered to be the result of strict one-to-one co-evolution between flower and insect