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The valorisation of dead stock – There is life in the old dog yet

This study follows reverse logistics thinking in the valorisation of dead stock from perishable by-products. Viable alternatives for the use of dead stock are found and the feasibility of their introduction evaluated through the building and application of a two-step model that links a two-stage production process generating by-products to staff scheduling problems in handling it. Model building is supported by empirical data from a poultry processing plant that had been collected through process maps, observations, and from databases of the case company. The model is also applied and solved for the case before suggesting general conclusions.

Keywords: perishable goods, valuation, dead stock, production planning, staff scheduling, reverse logistics

1. Introduction

Operational smoothing in process industries often leads to an accumulation of buffer as well as finished goods inventories. Inventory carrying costs aside, expiration dates also dictate the need for reducing finished goods inventories timely and efficiently. This paper evaluates alternative inventory management strategies while considering capacity constraints in materials handling. It is a specific case of integrating transportation and inventory decisions, which generally highlight the importance of inventory control (Viau *et al.*, 2009). It further focuses on the valorisation of inventory that is otherwise considered dead stock. The focus on the valorisation of dead stock follows Meade *et al.*'s (2007) call for more empirical research to understand the organisational practice of reverse logistics. Repeated calls have been made also more recently for more studies in reverse logistics, and various frameworks developed, whether from a decision-making (Setaputra and Mukhopadhyay, 2010; Hazen, 2011), or a stakeholder perspective (Kovács *et al.*, 2006). Inventories have been investigated in reverse logistics from the perspective of capacity constraints (Benedito and Corominas, 2011), total costs (John

and Sridharan, 2013), and even value recovery (Srivastava, 2008) in light of the flow of returns. The valorisation of stock has also been considered for by-products (Ilgin and Gupta, 2010) but not yet for dead stock.

In this paper, a two-step LP model is suggested that combines the needs of inventory management and staff scheduling in truck loading areas. Model building is supported through an empirical case, to which the model is also applied. A poultry processing plant is used as case. The model highlights the need for an integrated approach towards inventory management. The case implies that the reconsideration and management of “dead stock” is an interesting area of cost reduction without impacting on operational smoothing in manufacturing in spite of demand fluctuations.

The organisation of this paper is unique in that it follows the abductive research process of the study. The paper starts with a section on the research process before introducing data collection and problem identification in the empirical case. Next, the puzzling point and research focus are introduced. This is followed by a discussion of the valorisation of dead stock, and the development of the two-step LP model. The model is re-applied to the case before presenting and discussing conclusions. Apart from model development, the paper intends to contribute to the appraisal and valorisation of dead stock considering perishable items, and to the illustration how an abductive research process can be applied in logistics and operations management.

2. Research problem and process

Häkkinen and Hilmola (2005) contrasted case studies in logistics management that are largely descriptive to those in operations management, where they commonly follow an analytical methodology and produce normative results. At the same time, it has been regarded as a conundrum how to improve the empirical base of operations management (Fisher, 2007) as well as reverse logistics research (Meade *et al.*, 2007). Rather than

mere descriptions and/or models, case studies can also be used in a more structured way to identify current problems on the basis of which solutions are suggested. This is typical for inductive case studies, where the empirical study is used for problem identification and selection before abstracting theoretical contributions.

Induction clearly improves the empirical base of research. However, an even more pragmatic view on the usefulness of research is presented in the abductive research approach, which not only uses an empirical base but also applies the suggested theoretical contribution (e.g. model) to empirical data. Not surprisingly, Peirce, the father of abduction, has been labelled a pragmatist (cf. Bertilsson, 2004). Hence, Holmström *et al.* (2009) suggest the use of abductive reasoning to improve the usefulness and problem-solving abilities of design sciences. Abduction has been deemed particularly useful for tackling new problem areas, such as piracy (Min, 2011), or detecting what would constitute the actual problem at hand. Spens and Kovács (2006) present a step-wise description of the abductive research process consisting of

- (0) prior theoretical knowledge and
- (1) real-life observations,
- (2) a puzzling point, i.e. real-life observations not matching prior knowledge,
leading to
- (3) theory matching until
- (4) hypotheses are suggested, which are subsequently
- (5) applied in an empirical study before
- (6) suggesting new knowledge.

These steps are followed through in the study as well as the structure of the paper. The next subsections present the identification of the puzzling point and a feasibility

evaluation of various options in the study. This is followed by model development and application before concluding in new knowledge.

2.1 Initial case description and puzzling point

The study started as a participatory case study as in Olsson and Olander's (2005) action abductive research. The researcher was present in the case company (the poultry processing plant), had access to all databases, actively participated in meeting, observed activities in the factory and warehouse, and followed all processes related to incoming and outgoing material flows during a period of six months. This approach guaranteed good access to data. Process mapping was applied as a structured means of data collection. Process maps visualised the interconnectivities between the functional silos according to which the plant was organised and facilitated the conceptualisation of a puzzling point: until then, each functional silo (e.g. poultry production (hatching and growth), feed production, poultry processing, warehousing, sales, finance) was optimised separately. Problems then appeared in the finished goods warehouse where unsold frozen and fresh poultry products were left to expire.

In spite of a vast research focus on supply chain integration, the area of sales and operations planning that would actually facilitate internal integration is still underestimated (Schoenherr and Tummala, 2008; Tummala and Schoenherr, 2011).

Nonetheless, inventory management in the case company was considered separately from sales and manufacturing, and the warehouse manager, albeit having an overview of incoming and outgoing flows, had no influence on them.

Many factors influence on finished goods levels: target service level, demand fragmentation, production switching times, plant utilisation, seasonality, and negative sales trends are all factors that increase inventory levels of finished goods, while factors such as production flexibility and increased sales reduce it (Cachon and Olivares, 2010).

When comparing the effects of various inventory policies, Azadeh *et al.* (2011) reach the conclusion that any information sharing is better than none, but sharing forecasts outperforms the share of demand data. However, most inventory policies presuppose a pull system where orders are placed rather than push supply chains. Push systems are still typical for driving efficiency, for product returns (Srivastava, 2008), and have been reappraised from a resilience perspective (Christopher and Holweg, 2011). Food supply chains depending on harvests and growth cycles often employ push systems upstream while delivering against pull demand downstream (cf. Larson and McLachlin, 2011).

Also poultry production favours operational smoothing in spite of seasonal (e.g. turkeys for Thanksgiving) and fluctuating demand due to the long lead times of raising birds. Depending on husbandry system, the sex of the broiler and target meat levels, poultry is raised to 5-12 weeks of age for a broiler to be slaughtered but to 16-20 weeks for broiler to lay eggs, albeit with a downward trend of the average age of poultry to be slaughtered as a result of increasing feed conversion ratios (Proudfoot *et al.*, 1991). In the case company, turkey males were slaughtered at the age of 21-22, turkey females at 16, and chicken at the age of 12 weeks. Accordingly, production plans for poultry production and processing were made an astounding 26 weeks in advance, with actual input flows for processing fluctuating somewhat as a result of actual growth, death rates and overall health of the birds.

Beyond lead times and the resultant steady inbound flows to the processing plant, looking at cost drivers motivated operational smoothing further. Labour costs were the most important cost driver in the processing plant, with setup costs a distant second. Meat processing was the most labour-intensive activity. Keeping manufacturing processes running resulted in a reduction of idle times (for machinery and staff) and enabled manufacturing in two shifts. Ruling out production flexibility for reducing

finished goods inventories, potential positive sales was left as the only way to reduce inventories. Yet sales and inventory management had not been considered together in the case setting, and leftover inventory was considered “dead stock”.

Dead stock in this case was a considerable cost driver. Dealing with meat products, dead stock was considered hazardous waste in need of special, costly treatment. The issue at hand was not only to find alternative usages for dead stock but to evaluate the feasibility of their implementation these in light of capacity constraints in the warehouse. Warehousing space, though obviously limited, was less constraining than space and staff schedules in materials handling, which depended on the inbound flow of finished goods as well as on the arrivals of trucks picking up outgoing materials.

2.2 *The valorisation of dead stock*

Dead stock is foremost regarded as waste, which both total quality management and environmental management seek to minimise (Wu and Dunn, 1995, Corbett and Klassen, 2006). Dead stock results from demand fluctuations that lead to loss of sales on one hand, and product obsolescence and dead inventory on the other (Lin and Wang, 2011). From a waste management perspective, dead stock can also be studied through the lens of reverse logistics. Reverse logistics suggests two strategies for waste: proactive waste avoidance, also called pollution prevention, in the forward supply chain (through design for the environment, dematerialisation and environmental purchasing) and waste management, i.e. pollution control in the reverse supply chain (Corbett and Klassen, 2006). However, reverse logistics has mostly been concerned with the management of product and packaging returns, for whatever reason and in whatever condition (Rogers and Tibben-Lembke, 1998). When Fleischmann *et al.* (1997) first discussed inventories in reverse logistics, it was to highlight how returns shall be dealt with. Also now, John and Sridharan (2013) discuss inventory in reverse logistics when

looking at returned flow rates and cost minimisation. On the other hand, Ilgin and Gupta (2010) include inventory management under remanufacturing but highlight also the valuation of stock incl. by-products. In this case, valuation, or valorisation, is concerned with determining accurate measures for inventory holding costs (Ilgin and Gupta, 2010, Braglia and Frosolini, 2013).

But back to pollution prevention, the reverse logistics strategy that is most clearly linked to firm financial performance (King and Lenox 2002): Even from an environmental management perspective, high stock levels are not by all cost to be avoided. Instead, keeping higher stock levels can (a) offset emissions caused by frequent transportation, or can (b) be used for consolidation purposes, enabling less polluting as well as expensive transportation modes (Wu and Dunn, 1995). More recently, research has re-embraced the idea of using buffers to increase supply chain robustness (Vlajic *et al.*, 2012). Yet can waste avoidance strategies be applied in the case of dead stock? As Corbett and Klassen (2006) suggest, a first question to be asked is one of definitions – in their case of zero defects vs. zero waste, here as a distinction between dead stock and waste. Lin and Wang (2011) see dead stock as obsolete products and Alkheder *et al.* (2013) as a fraction of non-conforming items that are scrapped with no salvage value. More generally, Larson and DeMarais (1999) define dead stock as the category of stock that does not service demand. They further differentiate between dead stock that

- (1) does not serve to stimulate demand,
- (2) has no value for “normal” business purposes or
- (3) for which demand has not been registered for some time.

At the case company, dead stock is left after all demand has been fulfilled within its possible usage period. This occurs frequently in poultry processing due to divergent

flows with very different demand patterns for the various end products. Whilst e.g. drumsticks or wings may be in demand, livers and hearts do not follow the same demand pattern but are produced nonetheless. This complexity is exacerbated by the fact that the divergent flow production results in 1 920 different finished goods (and stock keeping units, SKUs) at the case company. Levels of dead stock naturally vary with demand for different across SKUs. Without demand from customers at different levels of the distribution channel this dead stock never leaves the facilities of the plant.

Nonetheless, as in reverse logistics, there may be a secondary market for these items. Reverse logistics considers secondary markets for used items, sometimes with the effect of fetching higher prices as the primary product (Stock *et al.*, 2002). Typically, it is the maximisation of recovery values of product returns and end of life products that is considered (Srivastava, 2008; Tan and Kumar, 2008; Ilgin and Gupta, 2010; Xanthopoulos and Iakovu, 2010). Dead stock is, however, comprised of original, unused items (Lin and Wang, 2011). In the case of divergent flow production, by-products make up for the majority of dead stock. In such a case, valorisation is not only a matter of determining inventory holding costs but also to devise strategies for what to do with such inventory. The main concern is to find alternative uses for these items that could generate revenue streams. Valorisation has been applied in this fashion to the use of end of life alkaline batteries in the production of new ones (Cucchiella *et al.*, 2013), the use of olive mill wastewater for thermal energy (Jeguirim *et al.*, 2012), or to the use of bakery waste in succinic acid production (Zhang *et al.*, 2013) – whereas value recovery is applied to all product returns (Srivastava, 2008; Tan and Kumar, 2008).

Firstly, any increase in sales can reduce dead stock as long as it is not classified as waste. Poultry processing facilities classify their stock as waste once it has “expired”. Expiry dates (sell-by dates) depend on the condition of the product (frozen or fresh) but

also on the legislation that applies to the plant. Sell-by dates are interesting from a pricing perspective as consumers are inclined to pay for freshness (Helo and Luomala, 2011). An obvious strategy to reduce dead stock from perishable goods is though, to issue items to orders based on their perishability date (Haijema, 2011). Before reaching its sell-by date, dead stock can also be sold and used as is in secondary markets. There are some interesting geographical differences in sell-by dates because some countries regulate sell-by dates generally (for manufacturers and stores) whilst others differentiate between a shorter sell-by period for manufacturers and a longer one for retail outlets. There are for example no federal regulations for sell-by dates in the US (USDA, 2011). Overall, the use of sell-by dates is controversial as consumers may confuse it with use-by (or best before) dates, leading to unnecessary waste – which in the UK alone amounted to 7.2 million tons of household food waste in 2010, not including food waste in the supply chain (WRAP, 2012). Thus in the UK, sell-by (or display until) dates are not noted on food packages any more even though they are technically used for determining until when manufacturers and retailers are allowed to sell food items (DEFRA, 2011). But whilst there have been several food labelling harmonisation attempts in the European Union (EU) since the establishment of the European Food Safety Authority (EFSA) in 2002, this relabeling initiative is unparalleled across the EU. For the case company (which delivers all across the EU), assessing differences in sell-by dates resulted in a viable secondary market for frozen products. However, this would have required major changes to the distribution system, differentiating between customers according to product sell-by dates. This was not deemed feasible to implement, hence further alternatives for dead stock needed to be considered.

Sell-by dates for food products differ also between their intended consumer groups, e.g. whether items are intended for human or animal consumption. Food

production for human consumption was the original market of the poultry producer. In other words, whilst dead stock had no value for human consumption as its original, “normal” business purpose (comp. Larson and DeMarais’ 1999 definition), selling it for animal consumption was still a possibility. This alternative would reduce costs substantially as the stock fetches a lower, residual price and at the same time eliminates the need for disposing of dead stock as hazardous waste. This applies the classic view on pollution control that is equalled with cost reduction (Corbett and Klassen, 2006) and reiterates the view of waste disposal being on the bottom of the hierarchy in reverse logistics which favours other methods to deal with materials (Carter and Ellram, 1998).

However, reappraising the option of selling poultry products for a different business purpose is comparable to the problem of by-products, the sales of which needs to be assessed in synergy with the primary product to avoid cannibalisation effects and lead to optimal results (Lee, 2012). In this case, the price for dead stock as raw material in animal food production was considerably lower, and the need for such raw material would not have triggered any change in production planning, hence there was no possibility for synergies or cannibalisation effects. At the same time, the option of selling dead stock to animal feed production was deemed feasible as it did not require a reorganisation of manufacturing nor packaging processes.

3. Model development

Once dead stock was identified as the problem, its general solution space needed to be defined. Minimising total costs was set as the overall objective. Constraints arose around the feasibility for handling and selling dead stock. Most importantly, the loading area was limited in space and available work force. Thus the model needed to further consider truck scheduling and loading. This led to a two-step optimisation model with production planning and inventory control on the one hand, and staff scheduling in the

loading area on the other. In this it is similar to Naphade *et al.*'s (2001) model that considered production scheduling, resource allocation and waste management in a mixed integer programming model, and Viau *et al.*'s (2009) joint consideration of inventory and transportation decisions.

3.1 Step 1: Production planning and inventory control

Production planning constitutes the first part of the problem. As typical for poultry processing, there were two stages ($j = 1, 2$) in the production process, primary processing as cutting poultry in divergent flow production, and further processing into e.g. into sausages and, breaded products. Primary processing has three possible outputs, finished goods, input to further processing, or waste. The two outputs of further processing are finished goods and waste. Waste, as noted above, results in disposal costs, which are weight but not product type-dependent.

Step 1 seeks to minimise total costs, which were comprised of disposal costs for hazardous waste and inventory holding costs. Other costs were deemed irrelevant for the study, as divergent flows resulted in standard, unavoidable production costs and as there were no setup times (and costs) to speak of. The objective function (1) is thus

$$\text{Minimise } v \sum_t a_t + h \sum_i \sum_j \sum_t w_{ijt} \quad (1)$$

where

v is disposal costs per kg

a is disposed products in kg

h is inventory costs (here standardised per kg), and

w is the amounts of a product on stock (in kg),

indexed with finished goods $i = 1$ to I . Production stages $j = 1$ to J distinguish between primary and further processing. $t = 1$ to T (in days) is used for a time index.

The divergent flow production for both input materials and production stages is modelled as input-output-equations (2) and (3), with q_{kjt} standing for raw materials, x_{ijt} for finished goods, and r_{kjt} for “rest”. The first two of these equations (2a and 2b) describe primary processing, followed with a description of further processing in (3a) and (3b). As all products are divergent from the same input material, a raw material index k is set for 1 = chicken and 2 = turkey.

$$q_{1,1,t} = x_{1,1,t} + x_{2,1,t} + q_{1,2,t+1} + r_{1,1,t} \quad (2a)$$

$$q_{2,1,t} = x_{3,1,t} + x_{4,1,t} + q_{2,2,t+1} + r_{2,1,t} \quad (2b)$$

$$q_{1,2,t} = x_{1,2,t} + x_{2,2,t} + r_{1,2,t} \quad (3a)$$

$$q_{2,2,t} = x_{3,2,t} + x_{4,2,t} + r_{2,2,t} \quad (3a)$$

Primary processing results in finished goods, input for secondary processing, and a rest. Further processing results in finished goods and rest. Rest is seen as dead stock, which is comprised of waste a as well as items that can be sold for animal food production, d . d is constrained by aggregate demand on the secondary market for poultry for animal consumption (see equations 4).

$$\sum_k \sum_j r_{kjt} = d_t + a_t \quad (4)$$

$$\text{Subject to } \sum_t d_t \leq D$$

Further problem constraints (5) are given as follows: Amounts produced and stored in any period cannot exceed demand (b_{ijt}) within the sell by date of the products for their original market (i.e. human consumption). This results in some adjustments between periods, but all demand is met from production or inventory. Stock balance equations (6) also apply, with given starting stock $w_{i,j,1} = STOCK_{ij}$.

$$x_{ijt} + w_{ijt} \leq \sum_{\tau=t}^{t+f_j} b_{ijt}^{new} \quad (5)$$

$$\text{subject to } b_{i,j,t+1}^{new} = b_{i,j,t+1}^{old} - x_{ijt} - b_{ijt}^{old}$$

$$b_{i,j,1}^{new} = b_{i,j,1}^{old}$$

$$\text{and } x_{ijt} + w_{ijt} \geq b_{ijt}^{old}$$

$$\text{Stock balance equations: } w_{i,j,t+1} = w_{i,j,t} + x_{i,j,t+1} - b_{i,j,t+1}^{old} \quad (6)$$

Non-negativity applies to a_t , w_{ijt} , q_{kjt} , x_{ijt} , r_{kjt} and both old and new b_{ijt} . The rest r is used as an input parameter for step 2 in the model.

3.2 Step 2: Staff scheduling for handling dead stock

Staff scheduling in the vehicle loading area constitutes the second part of the problem.

Here, the objective function (7) seeks to minimise unproductive time and related costs.

$$\text{Minimise } o \sum_t u_t \quad (7)$$

where

o stands for labour costs and

u for unproductive time,

indexed with $t = 1$ to T for each shift.

Unproductive time is all the time within a shift that has not been used for commissioning and loading vehicles. Capacity requirements for commissioning and loading vehicles are noted as k and l , with $j = 1$ to J (in the actual case 1 to 3 of vehicles coming for finished goods and type 4 for collecting rest) indexing vehicle types. s stands for the number of vehicles arriving in each shift. The total possible productive time has been set here with 7.17 hours per shift (with p denoting staff capacity), which takes all breaks for workers into account. Total unproductive time is given as (8)

$$7.17 p_t - \sum_t s_{jt} (k_j + l_j) = u_t \quad (8)$$

Importantly, all rest from step 1 in the model needs to be shipped out (9), whether for

waste processing or sold to the secondary market. Of course not more than actually produced or on inventory can be loaded on vehicles at any time. The parameter λ is used for a conversion of the rest r into actual vehicle loads.

$$\sum_t s_{4,t} = \left\lfloor \lambda \sum_t r_t \right\rfloor \quad (9)$$

$$\text{subject to } s_{4,t} \leq \left\lfloor \lambda \sum_{\tau=1}^t r_\tau \right\rfloor - \sum_{\tau=1}^{t-1} s_{4,\tau}$$

Non-negativity applies to u_b , $s_{4,t}$, p_b , k_t and l_t .

4. Application and results

The application of the developed theory – whether hypotheses, propositions, frameworks or models – is an important step in the abductive process. All steps prior to application, especially the theory matching process, stop short at theory matching and systematic combining as described by Dubois and Gadde (2002), but in lack of any application, the abductive process cannot close nor come to any conclusions (Spens and Kovács, 2006; Kovács and Spens, 2007). Therefore the study did not conclude in the suggestion of this combined inventory control and materials handling model but applied it to the case setting, following Holmström *et al.*'s (1999) example of applying their suggested model to the cases they derived it from.

Access to databases and gathering observational data facilitated the application of the model. The two production stages resulted in an astonishing 1 920 different finished goods that were aggregated into a solution matrix (i,j) in Table 1. Aggregations over SKUs are feasible for each valorisation alternative of dead stock (negative in disposal of hazardous waste, and positive in sales to secondary markets), as they only depended on the weight of processing “rest” but not on any other product specification.

< Please insert Table 1 about here >

The costs for waste processing (v) and the maximum amount that could be sold to secondary markets ($D = 800$ t/week) were given by the case company. Sell-by dates for each product were derived from their legal requirements, in this case being 1/3 of the perishability time of the product. Standardised production costs per product were also given. Starting stock levels and average inventory holding costs were calculated from historical data (data of the last week), resulting in $h=6.94$ /kg and overall $STOCK=2\ 038$ tons. The starting figures for raw materials could be approximated through the incoming broilers per day (30 000 chicken and 5 900 male vs. 6 500 female turkeys), their net weight (12, 16 and 24 kg) and an average loss during transportation. As a result, $q_{1,1,1}$ and $q_{2,1,1}$ were initialised with 360 000 and 245 600 kg respectively. Input for production stage 2 stems from output of stage 1, thus it needed to be calculated through the model. Aggregate demand was derived from historical data (see Figure 1), with clear peaks on Tuesday and Thursday for vehicle loading. Demand and production data for each product group and day was also available (see Appendix A for demand data).

<Please insert Figure 1 about here>

Once all data was gathered, the model was programmed and solved with commercial software. More surprising were the results for inventory in Table 2 in light of the constraints to sell dead stock in the secondary market.

<Please insert Table 2 about here>

Inventory levels overall resulted from differences in demand vs. production data.

Initially, waste was seen as accumulating by the end of the week. But once step 1 of the model was computed the constraints for using dead stock for sales in the secondary market of animal consumption did not appear to restrict the use of dead stock at all as they were lower than inventory levels in all time periods. It was left to determine whether staff scheduling in the loading area could be seen as a constraint.

Data for solving step 2 for the model came from observations of commissioning and loading times for different types of vehicles (see Appendix B). Historical data was consulted and corroborated with observations for determining arrival times of vehicles for each vehicle type and shift. As the model sought to minimise total costs, staff idle times were seen as opportunity costs and calculated as such with actual wages. There were some constraints in the loading of vehicles in each shift, e.g. export vehicles were only loaded during the first two shifts when quality control could be present, own vehicles visiting warehouses and wholesalers were only loaded in shifts two and three plus Saturday mornings (see Figure 2).

<Please insert Figure 2 about here>

Results were surprising again. Staff scheduling did not result in any constraints to serve the additional vehicles ($k = 4$) of the secondary market. Dead stock dealt with as hazardous waste could be completely eliminated. Overall, the results seem trivial but illustrate that against all expectations to the contrary, (a) dead stock is not useless but can still generate income, (c) the major cost driver of dead stock as hazardous waste could be eliminated, and (c) the model is feasible to implement without violating any capacity constraints at any stages of the product flow.

5. Conclusions

This research followed an abductive research process in that the main focus of the study was derived through a puzzling real-life observation – i.e. the problem on dead stock – a model was built on empirical observations, presupposing loops between model building and the case study context (also called theory matching, cf. Spens and Kovács 2006), and then, to finish the abductive process, the model was also applied once again to the case. As Holmström et al. (2009) observed, the abductive process did indeed improve the problem-solving ability of the research. The final step in the process would be to suggest new knowledge.

The application of the model to the case attested the computability of the model and its potential to come to viable solutions. Thus a first contribution of the research lies in the model itself that combines the aspects of production planning to staff scheduling in loading areas and thus, follows the material flow from production (with two production stages) through inventory management to the final dispatch of products. The model minimises total costs, of which, interestingly, dead stock that needs to be treated as hazardous waste turned out to be the main cost driver in this particular case. An important conclusion of the study is, therefore, that the valorisation of dead stock can be captured in a cost minimisation model, and that total costs are minimised if paying attention to dead stock. This is an alternative to traditional inventory management strategies that focus on cost minimisation but do not consider neither the alternatives for end products, nor the capacity constraints of handling them. Notwithstanding the particularities of the case, the model should be applicable to similar cases of divergent production with several production stages, which is not only typical in the agro-food industries but can be extended to other industries (e.g. metal industries) to look at co-products, by-products and as in this case, waste products that don't follow the same

demand pattern as the main product. In this, the study contributes to the stream of literature on divergent production as well as to closed loop supply chain literature, extending Ilgin and Gupta's (2010) valuation of by-products to finding new application areas for end products that cannot be used for their original intended purpose.

The paper illustrates how valorisation in the sense of finding alternative uses for dead stock contributes to revenue streams instead of costly disposal. Whilst the application of other reverse logistics concepts for perishable food items may be limited, valorisation builds on the finding of alternative markets both geographically and in terms of end users. That said, in this case there were no cannibalisation effects of by-products and waste products, which would need to be considered in other industries (see Lee's 2012 example). Also, actual capacity constraints can of course vary across industries – here we could neglect the capacity in the warehouse, but that may not be applicable in other cases. The model may thus need to be adapted to the particularities of the context and case to be applied to.

5.1 *Managerial implications*

The concrete results of the model application in the case company seem trivial but actually, go to illustrate that the main problem, as perceived by the company, can be solved even within the alleged capacity constraints of staff scheduling. It was indeed surprising that no waste was left at the end of the model application as we expected some residuals of dead stock not being able to be used otherwise. Basing the computational analysis on process maps, observations and data from case company databases improved not only the model and its real-life applicability but also the acceptance of the model and its results by the case company.

The study lends also to further implications beyond the case company. A first, important implication is the gap between problem perception and existence, which can

only be sorted out if the problem is not only modelled but the model is later also solved for the actual problem at hand. Here the abductive research process offers good opportunities to contribute to theory as well as practice. This underlines the alleged pragmatism of the abductive research approach (Bertilsson, 2004; Holmström *et al.*, 2009) and from a managerial perspective, calls for more research conducted this way.

5.2 *Avenues for further research*

Reverse logistics and closed loop supply chain management has focused relatively little on inventory management. Even though there is a focus to the value recovery of product returns (Srivastaa, 2008; Tan and Kumar, 2008), when it comes to the valorisation of end of use, or end of life items, reverse logistics research has much to learn from related disciplines such as conservation (see Jeguirim *et al.*, 2012) and green chemistry (Zhang *et al.*, 2013). Further, more interdisciplinary research is needed to bring insights from these disciplines back also to logistics and evaluate their implications for (reverse) logistics models.

This paper focused on the integration of transportation and inventory decisions in the area of inventory control. Research on waste management in this area is still scant, though as our results imply, could contribute to the finding of new revenue streams at the same time as minimising inventory holding costs. Further considerations of waste management in inventory holding may lead to interesting and innovative solutions.

Apart from the focus of the research, the paper illustrated how an abductive research process could be applied in logistics management. This research process is still little understood, and little applied in logistics, even though it brings ample possibilities to improve not just the theoretical contributions but also the managerial implications of logistics research.

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Table 1. Product groups of finished goods.

Production stage j	Product group	Chicken products (i,j)	Turkey products (i,j)
$j=1$	Fresh poultry	1,1	3,1
	Frozen good	2,1	4,1
$j=2$	Cold cuts	1,2	3,2
	Breaded products	2,2	4,2

Figure 1. Aggregate demand.

Table 2. Inventory levels and initial dead stock.

	Mon	Tue	Wed	Thu	Fri	Sat
w_{ijt}	733	18 742	38 531		123	7 107
Considered dead stock						8 454
Max demand for animal consumption	200 000	40 000	80 000	-	100 000	24 227

Figure 2. Idle time vs. vehicles served.

Appendix A: Demand data.

Product group (<i>i,j</i>)	Mon	Tue	Wed	Thu	Fri	Sat
(1,1)	15 206 / 15 206	39 371	20 209	49 407	31 075	-
(2,1)	112 130	103 401	139 736	111 506	107 460	80 185
(3,1)	34 180	83 999	42 591	104 157	65 507	-
(4,1)	68 882	63 519	85 840	68 497	66 012	49 273
(1,2)	39 825	96 712	49 635	121 364	76 334	-
(2,2)	91 789	84 638	114 389	91 275	87 968	65 652
(3,2)	24 185	58 734	30 142	73 712	46 366	-
(4,2)	18 670	17 217	23 269	24 090	17 894	13 370

Appendix B: Observation data.

Vehicle type <i>j</i>	Commissioning time <i>k</i> (in h)	Loading time <i>l</i> (in h)
1 = export	1.02	0.5
2 = own vehicles serving wholesalers in the country	0.44	0.75
3 = pick-up (vehicles of wholesalers and retailers)	0.28	0.42
4 = other (secondary market, disposal)	1.02	0.5