Complex models versus easy-to-use heuristics to manage retail operations

Karel van Donselaar and Rob Broekmeulen

Industrial Engineering & Innovation Sciences

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Content

- Gap between theory and practice
- Complex analytical models
- Easy-to-use heuristics
- The target audience
- Added value easy-to-use heuristics
- Added value complex analytical models
- Conclusions

The observations are based on 40 years of experience. Mostly in Inventory Control and Retail Operations. And mostly in close cooperation with Rob Broekmeulen

Gap between models and methods used in practice and developed in the literature

Reasons for the gap:

- Most inventory managers are unaware of the theory (e.g. replenishers in stores)
- Users do not understand basic concepts used in models, like standard deviation, pdf, integrals
- Users may distrust black box solutions
- Software based on complex models is hard to maintain (e.g. people change jobs)
- Users prefer simple methods, e.g. to communicate to other people in their organization who have no background in inventory control
- Scientists often use assumptions which do not hold in practice
- Top journals seem to favour (complex) analytical models

Gap between theory and practice

This raises the questions:

What is the added value of complex analytical models?
What is the added value of easy-to-use heuristics?

Complex analytical models

Scientific literature on Operations Management has a strong focus on solving **stylized problems** with analytical models, which often are **complex**.

Initially simple stylized problems are studied.

They provide simple solutions and first insights.

Then more complex models are developed, either to generalize (less stylized) or to adapt to more specific environments

Examples: Economic Order Quantity (EOQ) model

Inventory models with stochastic demand

Inventory models for perishable items

EOQ model

Basic model

Economic Order Quantity

$$Q^* = \sqrt{\frac{2DK}{h}}$$

Lessons learned, e.g.:

- Why it makes sense to not order very frequently
- Important to reduce fixed ordering costs (Just in Time trend)
- Total costs relative insensitive for small changes in Q

EOQ model

- Basic model
- >79,000 other papers on EOQ, including:
  - Effect of inflation on EOQ model with multivariate demand and partial backlogging and carbon tax policy
  - A model on an EOQ optimal ordering policy varying with time-dependent cubic demand and variable deterioration under delay in payment conditions

Economic Order Quantity

$$Q^* = \sqrt{\frac{2DK}{h}}$$

versus

$$TC_{1.1} = \frac{1}{T}\left[\begin{array}{l}(p-d)D\left(\frac{(\mu-\alpha)}{r}\left(1-e^{-rT}\right)+\frac{\alpha}{\mu(\mu+r)}\left(e^{\mu T}-e^{-rT}\right)\right)-A-\lambda A_e-\frac{(c+d+\lambda C_e)D}{\mu}\left(e^{\mu T}-1\right)- \\ \frac{cD}{\mu}\left((g+\lambda h_e)\left(\frac{e^{\mu T}}{(\mu+r)}+\frac{\mu e^{-rT}}{r(\mu+r)}-\frac{1}{r}\right)+h\left(\frac{\mu e^{-rT}(\mu+2r)}{r^2(\mu+r)^2}+\frac{Te^{-rT}}{r(\mu+r)}+\frac{e^{\mu T}}{(\mu+r)^2}-\frac{1}{r^2}\right)\right) \\ -\frac{ci_pD}{\mu}\left(\frac{e^{(T-M)\mu-rM}}{(r+\mu)}+\frac{\mu e^{-rT}}{r(\mu+r)}-\frac{e^{-rM}}{r}\right)+ \\ pi_eD\left[\left(1-\frac{\alpha}{\mu}\right)\left(\frac{1}{r^2}-\frac{e^{-rM}}{r}\left(M+\frac{1}{r}\right)\right)+\frac{\alpha e^{\mu T}}{\mu(r+\mu)^2}\left(1-e^{-(\mu+r)M}\left(M(\mu+r)+1\right)\right)\right]\end{array}\right] \quad (5)$$

$$TC_{1.2} = \frac{1}{T}\left[\begin{array}{l}(p-d)D\left(\frac{(\mu-\alpha)}{r}\left(1-e^{-rT}\right)+\frac{\alpha}{\mu(\mu+r)}\left(e^{\mu T}-e^{-rT}\right)\right)-A-\lambda A_e-\frac{(c+d+\lambda C_e)D}{\mu}\left(e^{\mu T}-1\right)- \\ \frac{cD}{\mu}\left((g+\lambda h_e)\left(\frac{e^{\mu T}}{(\mu+r)}+\frac{\mu e^{-rT}}{r(\mu+r)}-\frac{1}{r}\right)+h\left(\frac{\mu e^{-rT}(\mu+2r)}{r^2(\mu+r)^2}+\frac{Te^{-rT}}{r(\mu+r)}+\frac{e^{\mu T}}{(\mu+r)^2}-\frac{1}{r^2}\right)\right) \\ +pi_eD\left(\frac{1}{r^2}\left(1-\frac{\alpha}{\mu}\right)\left(1-e^{-rT}(1+Tr)\right)+(M-T)T-\frac{\alpha e^{-rT}}{\mu}\left(\frac{T}{(\mu+r)}-\frac{1}{(\mu+r)^2}\right)\right)\end{array}\right] \quad (6)$$

Inventory models with stochastic demand

Started with single non-perishable product in a single echelon system

Basic Base-Stock Policy model with Base−Stock Level equal to

$$L \cdot \mu + k \cdot \sigma\sqrt{L}, \quad \text{k solved from } \Phi(k) = P1$$

Stylized model: Continuous review, no lot-sizing, normal demand, demand i.i.d., P1-service, infinite supply, constant lead time, backordering, etc.

Extending to Compound Poisson and Lot-sizing already leads to

$$E[H(x,t)] \simeq (E[\bar{A}]-E[A]) \left[x - \int_0^x (x-y) \right] dF_{D(0,t]}(y) + E[A] \left[\int_0^x (x-y)\, dM(y) - \int_0^x \int_0^{x-y} (x-y-z)\, dM(z)\, dF_{D(0,t]}(y) \right] \quad (4.37)$$

Inventory models for perishable items

Analysis of basic models provide important insight:
Perishable inventory models are very hard to analyse.

- Started with periodic review systems: Often assuming zero lead time
- Then focus on continuous review systems, allowing less stylized models (e.g. positive lead time and/or lot-sizing)
- Then back to periodic review systems to better reflect reality; more heuristics, tested with simulation. E.g. new replenishment logic (e.g. BSP-low and EWA)

Due to increased societal relevance and awareness, recent focus is turned more to models/heuristics which actually help to reduce food waste in practice

Easy-to-use heuristics

Easy-to-use heuristics can be

- Result from basic models: E.g. EOQ and $S = L\mu + k\sigma\sqrt{L}$ with $\Phi(k) = P1$
- General concepts: ABC classification combined with Service differentiation
- Tailored heuristics

Different interpretations of ‘Easy-to-use’:

- Simple back-of-the envelope formula which can be understood by non-experts
- Formulas expressed in standard Excel functions
- Black box for user, but implemented in Excel via tailored Excel functions

Different ‘easy-to-use’ interpretations: an example

To estimate the % of waste for a perishable item, two ‘easy-to-use’ solutions:

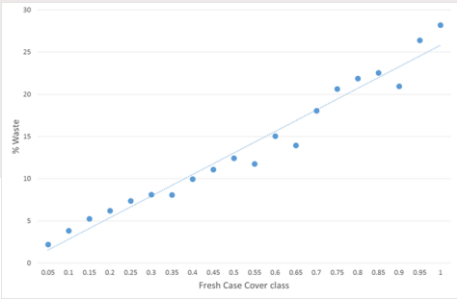
First solution: %Waste as a linear function of multiple basic variables (like σ/μ) and some expectations of functions of stochastic variables.

$$z_{regr} = \beta_0 + \beta_1 \cdot \frac{\sigma}{\mu} + \beta_2 \cdot \frac{ss+Q-1}{\mu} + \beta_3 \cdot \left(\frac{Q}{\mu} - R\right)^+ + \beta_4 \cdot \left\lceil \frac{s}{Q} \right\rceil \cdot \frac{Q}{\mu} + \beta_5 \cdot (1-P_2^*) + \beta_6 \cdot z^A + \beta_7 \cdot z^B$$

$$z^A = \frac{1}{\rho\mu} \cdot E\left[\left(\left\lceil \frac{s-[L+m-\rho]\cdot\mu}{Q} \right\rceil \cdot Q - D_\rho\right)^+\right]$$

Implemented in Excel or Python file using tailored functions

Second solution: Fresh Case Cover (FCC) $FCC = \frac{Q}{m\mu}$



Target audience

For whom do we write our papers?

- Fellow researchers to provide them new insights or new methodologies
- Practitioners to apply the results in practice to improve performance

Two different types of practitioners:

- Very skilled and knowledgeable experts in large companies
- Managers and End-users with little to no knowledge about advanced concepts

Even in large companies we encounter restraint due to limited domain knowledge and/or software requirements -> also then easy-to-use solution often preferred

Added value easy-to-use heuristics

Added value for practitioners: the chance of getting research results implemented increases with

- Easy-to-understand heuristics
- Easy-to-communicate heuristics
- Easy-to-calculate heuristics
- Evidence that heuristics are already applied successfully
- Solid testing on datasets which align with empirical data
- Developing the heuristic in cooperation with a company (e.g. Kuhn and Sternbeck)
- Strong performance of the heuristics

Added value complex analytical models

- Complex analytical models can be implemented in companies with highly skilled employees and/or consultants
- Analytical models can help to identify optimality conditions and/or bounds for the decision variables. These can be used when testing heuristics.

  E.g. Kouki, Jemai and Minner show for perishables optimal Q <= (m+L)*mu.
  Limitation: is conditional, e.g. continuous review and stock-based policy
- Analytical models can help to develop heuristics

  The modelling steps or results used in analytical models can be applied in combination with simplifying approximations to provide a simple heuristic

Analytical models can help to develop heuristics

Example 1: if a result is derived for continuous review model, it can be tested whether the same result holds for a periodic review system, when replacing L by R+L

Example 2: An easy-to-use approximation for the service in *2-echelon* inventory systems *with lot-sizing* (Van Donselaar, 1990) is derived from combining 2 basic analytical models:

- the Clark and Scarf model for *2-echelon* systems *without lot-sizing* and
- the Hadley and Whitin model for a *1-echelon* system *with lot-sizing*

To turn this into an easy-to-use heuristic, a simplifying assumption is made on the distribution of the relevant inventories.

- The heuristic is used by a consultancy company to advise retailers on their distribution networks
- Same heuristic is used to develop an easy-to-use estimator for fill rate for perishables

Analytical models can help to develop heuristics

Example 3:
To estimate the % of waste for a perishable item, some variables in the regression function are the result from an analytical model.

$$z_{regr} = \beta_0 + \beta_1 \cdot \frac{\sigma}{\mu} + \beta_2 \cdot \frac{ss+Q-1}{\mu} + \beta_3 \cdot \left(\frac{Q}{\mu} - R\right)^+ + \beta_4 \cdot \left\lceil \frac{s}{Q} \right\rceil \cdot \frac{Q}{\mu} + \beta_5 \cdot (1-P_2^*) + \beta_6 \cdot z^A + \beta_7 \cdot z^B$$

$$z^A = \frac{1}{\rho\mu} \cdot E\left[\left(\left\lceil \frac{s-[L+m-\rho]\cdot\mu}{Q} \right\rceil \cdot Q - D_\rho\right)^+\right]$$

-> Many easy-to-use heuristics are based on results from analytical models

TU/e

Considerations on developing easy-to-use heuristics

Some experience may be needed to identify how to simplify while still achieving high performance

➔ After tenure track or under supervision of/in cooperation with senior scientist?

Journals may prefer if easy-to-use heuristics are supported by testing on empirical data or having proof of success in practice

➔ Check whether a cooperation with industry is possible (takes time)

The rewards are not only a publication but also adding value to society!

Conclusions

- Both easy-to-use heuristics and complex analytical models can add value
- Not all complex analytical models add value for practice
- Practice often prefers to apply (the lessons from) the simple analytical models and heuristics, despite its shortcomings.
- We should not underestimate their added value in education, communication and ease-of-implementation

- What does this imply for your next research project?