Simple Inventory Policies as Diagnostics

Exploration of optimal inventory control of A4 Materiel Class

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Defence R&D Canada
Centre for Operational Research and Analysis

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Canada

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Abstract

We apply a filter method, based on continuous review (Q,r) inventory policies, to the Department of National Defence's highest value and fastest moving inventory. The filter flags potentially problematic inventory levels in DND's holdings. Our results provide DND with a method that carefully targets the most problematic inventory issues, both in cost and total affected part numbers, for further study and examination. We apply our methods to the current A4 Material Class data, and we identify 17 out of 136 items which have inventory levels at least a factor of three above an optimal (Q,r) policy with a 99% fill rate. Our results call for more detailed Directorate Materiel Group Operational Research study and a mandate to work closely with Director General Materiel Systems and Supply Chain staff on inventory rationalization.

Résumé

Une méthode de filtrage établie en fonction des politiques de vérification continue d'inventaire (Q,r) est appliquée aux stocks (mouvement plus rapide et valeur supérieure) du ministère de la Défense nationale (MDN). Le filtre met en évidence les niveaux potentiellement problématiques des stocks du MDN. Les résultats fournissent au Ministère un moyen de cibler avec soin les enjeux les plus problématiques associés aux stocks, soit les coûts et le numéro des articles touchés pour un examen approfondi. Les méthodes sont actuellement appliquées aux données de la classe de matières A4. Des 136 articles examinés, 17 ont un niveau d'au moins 3 fois supérieur à ce que la politique optimale indique (Q,r), avec un taux d'utilisation de 99 %. À la suite des résultats obtenus, la Direction de la recherche opérationnelle - Groupe des matériels doit mener une étude plus approfondie et collaborer étroitement avec la Direction générale - Systèmes de matériel et chaîne d'approvisionnement sur la rationalisation des stocks.

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Executive summary

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David W. Maybury; DRDC CORA TM 2012-275; Defence R&D Canada – CORA; December 2012.

Over the last 15 years, the Department of National Defence (DND) has launched numerous initiatives examining inventory problems and record-keeping, yet significant problems remain. Under the direction of the DCOS(Mat), a new ADM(Mat)-wide initiative was developed to reduce national inventory, increase awareness of materiel flow, and build a long term approach to rationalize inventory holdings. In August of 2011, DCOS (Mat) asked the Directorate of Materiel Operational Research (DMGOR) to assist with ADM(Mat)'s inventory rationalization efforts.

DND has rolled out Defence Resource Management Information System (DRMIS) with a utility called Distribution Resource Planning (DRP) which allows users to extract a wealth of detailed inventory data down to the line item stock number level. Furthermore, ADM(Mat) has proceeded with a new stock taking initiative to give DND a more accurate picture of DND's inventory holdings. We can now apply inventory control methods to the aggregate data.

In the spirit of applying simple models to generate insight into complicated problems, we use a filter on DND's inventory, based on optimal reorder policies. We apply the filter method to all DRP A4 Materiel Class designated items (highest value, fastest moving items in inventory) as of March 30, 2012. Using the demand history over four years of monthly data, we calculate the optimal reorder point and reorder quantity for each item while ensuring a 99% fill rate (on average 1 in 100 replenishment lead times will experience a stock out – approximately once per 15 years for each item studied – in which demands will go into back order). Conservatively, we find that 17 items out of a possible 136 A4 Material class call for a better understanding of DND's current inventory policy.

We display the key results in figure 1. We see that DND's actual four year average inventory, represented by the top of the maroon bar, widely exceeds the 99% fill rate optimal average inventory represented by the green region in each bar (the blue bars represent a sub-optimal inventory holding). The average inventory across these 17 items sits at a level at least a factor of three greater than what we would expect from a simple optimal policy. Using a 6% interest rate, the 17 items constitutes $5.2M in holding costs. The optimal policy, with a 99% fill rate and an ordering cost set at ten times the annual holding costs (yielding an expectation of one to five years between replenishment orders across the 17 items) has a holding cost of only $1.3M. We see that the high inventory position on these 17 items costs DND nearly an extra $4M per year under our assumptions. The inventory items flagged by this analysis are:

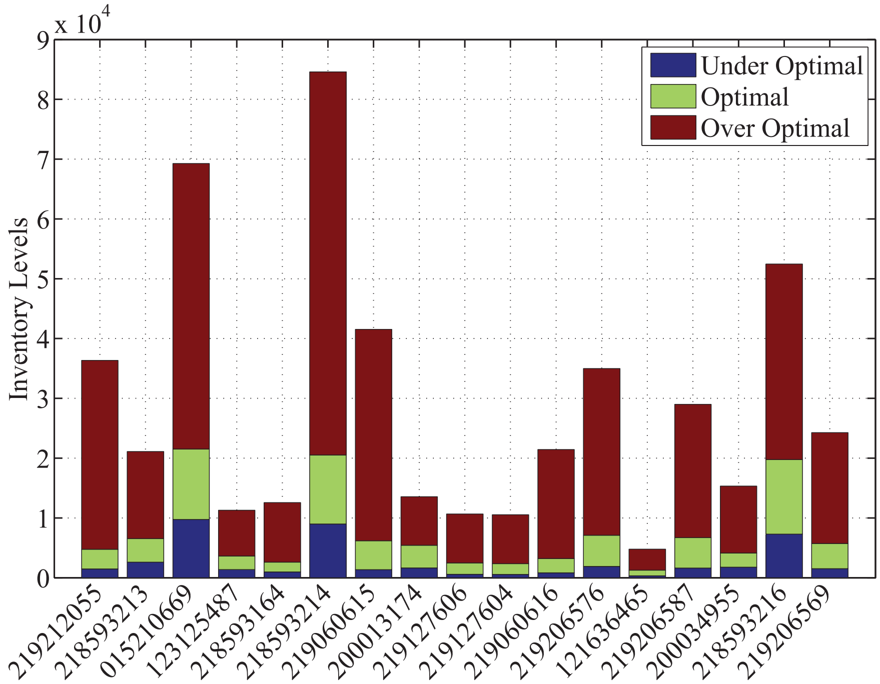

Figure 1: A4 Materiel Class Inventory flagged by the filter method by part number. The green portion of each bar represents the range of the average inventory of all solutions along the optimal frontier with a 99% fill rate while the blue region of each bar gives an average inventory that fails to deliver a 99% fill rate. The top of the maroon bar represents DND's actual four year average inventory level.

- 219212055 Sonobouy
- 218593213 Frame Section, Tent
- 015210699 Canister, Oxygen Generating, Breathing App
- 123125487 Track Shoe, Vehicular
- 218593164 Tent Section
- 218593214 Purlin, Tent
- 219060615 Mask, Chemical-Biological
- 200013174 Rucksack, Internal Frame
- 219127604 Helmet, Ground Troops-Parachutists
- 219090916 Mask, Chemical-Biological

- 219206576 Trouser, Camouflage Pattern
- 121636465 Wheel, Solid Rubber Tire
- 219206587 Coat, Camouflage Pattern
- 200034955 Brassard, Fragmentation Protector
- 218593216 Pin, Tent
- 219206569 Trouser, Camouflage Pattern.

Our results call for more detailed DMGOR study on inventory control, and a mandate from senior decision makers to work closely with DRP champions, Equipment Program Manager (EPM) personnel, and Director General Materiel Systems and Supply Chain (DGMSSC) staff. Once our filter method identifies an item or set of items for potential excess inventory holdings, we require a further understanding of the underlying issues. Higher fidelity modelling, contractor lead time uncertainty, network and staging effects, and supplier relations represent the next layers in the study. We can only accomplish this goal with a clear mandate to integrate our study with DGMSSC.

Sommaire

Simple Inventory Policies as Diagnostics

David W. Maybury ; DRDC CORA TM 2012-275 ; R & D pour la défense Canada – CARO ; décembre 2012.

Au cours des 15 dernières années, le ministère de la Défense nationale (MDN) a lancé diverses initiatives visant à examiner les problèmes de stocks et la collecte de données, mais d'importants problèmes demeurent. Une nouvelle initiative à l'échelle du SMA(Mat) a été mise sur pied, sous la direction du SCEM(Mat), afin de réduire immédiatement les stocks nationaux et d'accroître la sensibilisation à l'égard du mouvement du matériel, tout en développant une approche à long terme afin de rationaliser les stocks. En août 2011, le SCEM(Mat) a demandé à la Direction de la recherche opérationnelle - Groupe des matériels (DROGM) de soutenir les efforts de rationalisation des stocks du SMA(Mat).

Le MDN a mis en place le Système de gestion de l'information sur les ressources de la Défense (SGIRD) dont la fonctionnalité de planification des ressources de distribution (PRD) permet aux utilisateurs d'extraire de nombreuses données d'inventaire détaillées, incluant le niveau des stocks. En outre, le SMA(Mat) a créé une nouvelle initiative d'inventaire afin d'élaborer un tableau plus précis des stocks du MDN. Il est maintenant possible d'appliquer les méthodes de vérification des stocks aux données d'ensemble.

Un filtre est utilisé pour les stocks du MDN, en fonction des politiques de réapprovisionnement optimales, dans le but d'appliquer de simples modèles pour obtenir un aperçu des problèmes complexes. La méthode de filtrage est employée pour tous les articles désignés (stocks avec un mouvement rapide et une valeur supérieure) de la classe de matières A4 du PRD en date du 30 mars 2012. À l'aide de l'historique de la demande des données mensuelles sur une période de 4 ans, le seuil et la quantité de réapprovisionnement optimal de chaque article sont calculés, tout en assurant un taux d'utilisation de 99 pour cent (environ 1 réapprovisionnement sur 100 sera en retard - soit 1 fois tous les 15 ans pour chaque article examiné - occasionnant ainsi une rupture de stock). Au minimum, 17 des 136 articles examinés de la classe de matières A4 nécessitent une meilleure compréhension de la politique actuelle du MDN en ce qui concerne les stocks.

Les principaux résultats sont présentés à la 2. Comme le montre le haut de la barre marron, les stocks moyens du MDN sur une période de 4 ans dépassent largement le taux d'utilisation de 99 pour cent des stocks moyens optimaux représentés par la partie verte de chaque barre (la partie bleue constituant des stocks sous-optimaux). Les stocks moyens de ces 17 articles surpassent d'au moins 3 fois la politique optimale simple à laquelle il faudrait s'attendre. Avec un taux d'intérêt de 6 pour cent, la valeur du coût de possession de ces 17 articles s'élève à 5,2 M$. Selon la politique optimale, ce coût de possession est de seulement 1,3 M$, en tenant compte d'un taux d'utilisation de 99 pour cent et d'un coût

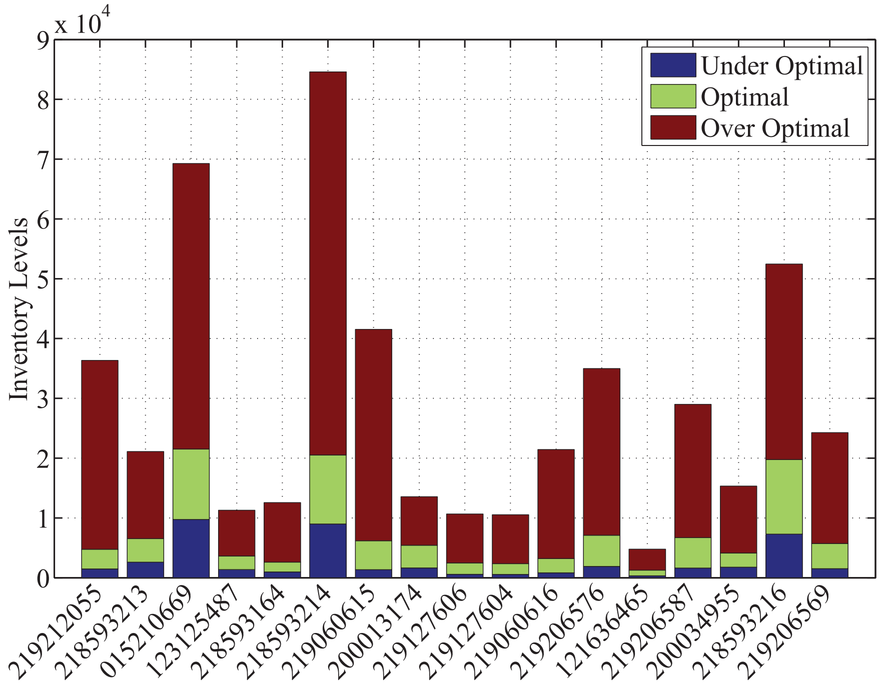

Figure 2: Stocks de la classe de matières A4 mis en évidence par numéro d'article à l'aide de la méthode de filtrage. La partie verte de chaque barre représente les stocks moyens de toutes les solutions qui se trouvent le long de la limite optimale, avec un taux d'utilisation de 99 pour cent. La partie bleue constitue les stocks moyens dont le taux d'utilisation est inférieur à 99 pour cent. Le haut de la barre marron correspond au niveau actuel des stocks moyens du MDN sur une période de 4 ans.

d'approvisionnement 10 fois supérieur à celui associé aux stocks annuels (un à cinq ans entre les commandes de réapprovisionnement pour les 17 articles). Tout porte à croire que les niveaux de stocks élevés de ces articles coûtent au MDN près de 4 M$ de plus par an. L'analyse a identifié les articles d'inventaire suivants :

- 219212055 Bouée acoustique
- 218593213 Armature de tente
- 015210699 Cartouche filtrante génératrice d'oxygène pour appareil respiratoire
- 123125487 Patin de véhicule
- 218593164 Section de tente
- 218593214 Panne de tente

- 219060615 Masque de protection chimique et biologique
- 200013174 Armature interne du havresac
- 219127604 Casque pour les troupes au sol et les parachutistes
- 219090916 Masque de protection chimique et biologique
- 219206576 Pantalon de camouflage
- 121636465 Roue à bandage plein
- 219206587 Veste de camouflage
- 200034955 Brassard anti-fragmentation
- 218593216 Goupille pour tente
- 219206569 Pantalon de camouflage

À la suite des résultats obtenus, la DROGM doit mener une étude plus approfondie sur le contrôle des stocks. De plus, les principaux décideurs ont pour mandat de collaborer étroitement avec les champions de la PRD, de même que le personnel de la Gestion du programme d'équipement (GPE) et de la Direction générale - Systèmes de matériel et chaîne d'approvisionnement (DGSMCA). Lorsque la méthode de filtrage identifie les stocks possiblement excédentaires d'un ou plusieurs articles, il faut examiner davantage les enjeux sous-jacents. La modélisation à fidélité améliorée, l'incertitude liée aux délais des entrepreneurs et les relations entre les fournisseurs, de même que les effets du réseau et du positionnement constituent les prochaines étapes de l'étude. Cet objectif peut être atteint uniquement avec un mandat clair visant l'intégration de l'étude au sein de la DGSMCA.

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1 Introduction

Since at least 1988, the Auditor General of Canada has questioned the Department of National Defence's (DND) inventory and sparing policies [1]. While military inventory allows DND to accomplish its mandate, excess inventory represents lost opportunity which degrades the effectiveness of the Canadian Forces. By applying optimal control theory and dynamic programming, we construct a filter that identifies problematic inventory levels, providing a first step in concretely addressing the Auditor General's concerns. Our filter methods allow DND to carefully target the most problematic inventory issues, both in cost and in total affected part numbers, for further study.

DND has a total inventory of $12 billion of which $5 billion resides in 642K materiel line item stock numbers [2]. Of the $5 billion in line items, approximately $1.5 billion, representing over 200K items, sit in dormancy longer than 4 years. As a point of comparison, Canadian Tire has less than $1 billion in merchandise inventories at any given time [3]. While DND has a unique mandate, separate from anything in the private sector, our large military inventory demands that we carefully understand how inventory contributes to the Canadian Forces' success.

Over the last 15 years, DND has launched numerous initiatives [4], [5], and [6] examining inventory problems and record-keeping, yet significant problems remain. Under the direction of the DCOS(Mat), a new ADM(Mat)-wide initiative [2] was developed to reduce national inventory, increase awareness of materiel flow, and build a long term approach to rationalize inventory holdings. In August of 2011, DCOS(Mat) asked the Directorate of Materiel Group Operational Research (DMGOR) to assist with ADM(Mat)'s inventory efforts.

In April 2010, DND rolled out Defence Resource Management Information System (DRMIS) with a utility called Distribution Resource Planning (DRP) which allows users to extract a wealth of detailed inventory data down to the line item stock number level. Furthermore, ADM(Mat) has also proceeded with a new stock taking initiatives to give DND a more accurate picture of DND's inventory holdings. We can now apply inventory control methods to the aggregate data.

At its heart, inventory management is about tradeoffs. We use inventory to satisfy consumption demands while we wait for the arrival of newly ordered materiel. Thus, in effect, all inventory control is about time management. Inventory holdings balance the costs and benefits of satisfying current demand requests out of on-hand stock against the costs imposed by waiting for replenishment. Properly balancing the competing objectives of the lost opportunity of capital stored in inventory against the costs of unsatisfied demand requests – which is implicit in all inventory problems – requires the application of operational research methods.

Since the seminal work of Harris in 1913 on economic lot sizing [7], operational research on inventory control methods have developed highly specialized models, from Material Resource Planning (MRP) to Just-in-Time (JIT), for handling a wide assortment of specific inventory needs (see for example, [10]). In the 1950s, researchers applied dynamic programming to inventory theory [8] and established the optimal solutions for a series of well posed tractable inventory problems. In particular, [9] demonstrated that simple order-up-to policies based on the current inventory position offer an optimal solution to a wide host of inventory problems with and without stochastic demand.

In the spirit of using simple models to generate insight into complicated problems, we use a filter on DND's inventory, based on continuous review (Q,r) policies (for review, see [10]) , which tell us to order a replenishment quantity, Q, each time the inventory position falls to the reorder point, r. The (Q,r) policy represents the optimal inventory policy for the class of problems we consider in this paper. As an example of a (Q,r) policy in action, consider figure 3. In this example, we have an inventory policy that orders four items every time the inventory position falls to four or less items. The inventory position is the sum of the inventory on-hand (which can be negative, indicating backorders) and the items on order that are yet to arrive. In figure 3 we see that we start with five items in inventory with no orders. Thus, on-hand inventory and the inventory position match. In the first time period we observe a demand of 1 item which drops the inventory position drops to four items, thereby triggering a replenishment order of four items. As a result of the ordering, the inventory position instantly jumps to eight items. Notice the delay of two time units between an order and the arrival of the item in inventory. The delay, or lead time, causes the inventory position to depart from the inventory on-hand. In principle, if we observe a sufficiently large demand during a time unit, the on-hand inventory will drop below zero, thus generating backorders, and we will have to wait for the replenishment order's arrival to satisfy the unfilled demand. We see that the inventory position varies between five and eight items, but the on-hand inventory can fall below five items as demands continue to arrive while we wait for the replenishments.

We apply a (Q,r) filter method to all A4 Materiel Class designated items (highest value, fastest moving items in inventory) in the DRP as of March 30, 2012. Using the demand history over four years of monthly data, we calculate the optimal reorder point and reorder quantity for each item while ensuring a 99% fill rate (on average 1 in 100 replenishment lead times will experience a stock out in which demands will go into back order). Conservatively, we find that 17 items out of a possible 136 A4 Materiel class items call for a better understanding of DND's current inventory policy.

AIM: This study seeks a mandate from senior decision makers, calling DMGOR to work closely with DRP champions, Equipment Program Management (EPM) personnel, and Director General Materiel Systems and Supply Chain (DGMSSC) staff on developing optimal inventory control policies. Our filter method identifies items with potentially excessive inventory holdings. This study represents a blueprinting device for moving forward on higher fidelity modelling, supply chain management analysis, and inventory rationalization. We can only bring our inventory solutions to fruition with a clear mandate to integrate our study with DGMSSC involvement.

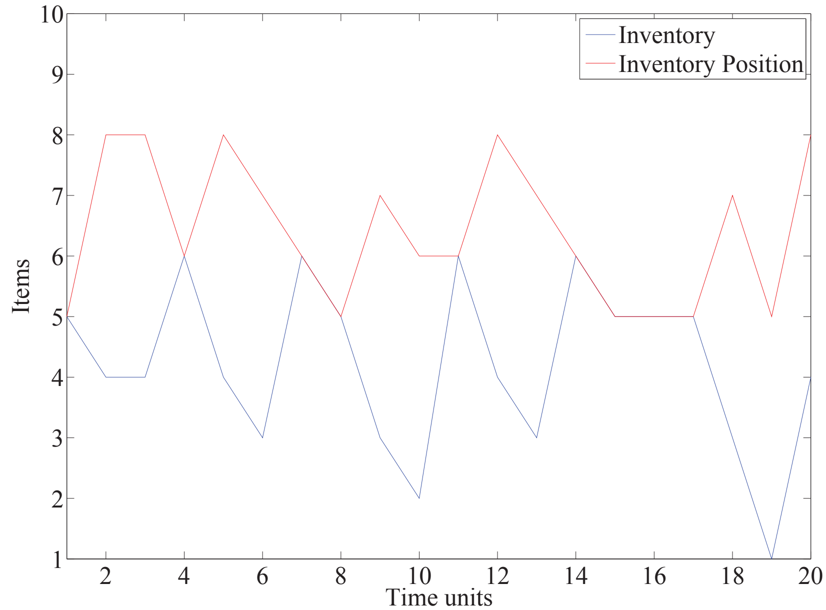

Figure 3: Example of a $(Q = 4, r = 4)$ policy. Notice that the lead time is two time units.

2 Results

We apply (Q,r) policies to the A4 Materiel Class items under the following assumptions:

- All items are independent from one another;
- Item demands are independent and identically distributed;
- Material is consumed through demands (no returns);
- Backordering only occurs if on-hand inventory across DND becomes exhausted;
- Estimated demand distribution based on 48 months of data is sufficiently robust;
- Lead times are constant (rounded up to the nearest whole month); and
- A fill rate of 99% is required (on average, 1 in every 100 lead times witnesses a stock out).

Reality violates all of our assumptions: parts interact (demand for one component affects others in inventory); backordering can occur even if DND has inventory as network transportation costs can make satisfying a demand from inventory too costly; demand can be unstable; etc. Our assumptions cast the problem in a tractable form. We use our model to signal the worst problems in inventory such that violations of our assumptions cannot account for the wide departure from the model's optimal inventory position and DND's holdings.

The formulation of the (Q,r) inventory policy balances ordering costs, or setups, against holding costs (for details see, [10]). Intuitively, costly ordering drives increases in inventories, while high holding costs push inventory down. The holding cost represents lost opportunity as capital is tied up and unavailable, and the ordering cost is the transaction cost associated with replenishment. Balancing these two costs results in a fill rate (the fraction of the time that demands are satisfied from inventory).

In many cases, estimating costs can be extraordinarily difficult. Setup costs might include costs associated with forklift movements, machine resets, and manufacturing downtime, all of which all do not explicitly involve actual payments. Holding costs contain at least interest costs, but they also contain storage facility costs, which can make accurate estimation problematic. Furthermore, balancing stock out against the cost of losing customer goodwill proves challenging even in the best of circumstances. When cost estimates prove too difficult to obtain, or prove too unreliable, inventory managers can focus on the fill rate or backorder level as an objective.

The A4 Materiel class data contains the part price for each item and thus we can compute a lower bound on holding costs through interest rate calculations. We use an annual interest rate of 6% for the capital stored in inventory. Our choice of the interest rate does not affect the results in this paper, it simply provides an estimate of the holding costs relative to the current and alternative policies. Long term, interest rates average about 6% even though the current short term discount rate is approximately 1%. We have no way of estimating the ordering or step costs without detailed discussions with the DRP champions and EPM personnel on a item per item basis. Thus, we cannot use the the (Q,r) model to balance holding costs against ordering costs. Instead, we focus on a set of solutions, called a frontier, which offer a fill rate of 99%.

To construct our filter method, we empirically build the cumulative distribution function for each component over monthly demand, rounded up to the nearest whole month. We convolve the monthly results to give the cumulative distribution of demand in each lead time, again rounded up to the nearest month. We make no attempt to parametrically model the stochastic demand distribution function. By focusing on non-parametric methods, we introduce fewer modelling errors in our filter, and our methods are robust against changes as new data emerges.

Our filter method works by examining the frontier of solutions that attain a 99% fill rate. The range of the (Q,r) policy solutions run from the base stock policy (order a new item with every demand) to a policy with an ordering cost ten times larger than the annual holding cost at 6% interest. Searching along the frontier, we flag an item if the empirically observed four year average inventory exceeds the highest possible inventory position anywhere along the frontier, namely $Q+r$.

Our method flags the following items 17 items:

- 219212055 Sonobouy
- 218593213 Frame Section, Tent
- 015210699 Canister, Oxygen Generating, Breathing App
- 123125487 Track Shoe, Vehicular
- 218593164 Tent Section
- 218593214 Purlin, Tent
- 219060615 Mask, Chemical-Biological
- 200013174 Rucksack, Internal Frame
- 219127604 Helmet, Ground Troops-Parachutists
- 219090916 Mask, Chemical-Biological
- 219206576 Trouser, Camouflage Pattern
- 121636465 Wheel, Solid Rubber Tire
- 219206587 Coat, Camouflage Pattern
- 200034955 Brassard, Fragmentation Protector
- 218593216 Pin, Tent

- 219206569 Trouser, Camouflage Pattern.

We display the results in figure 4. We see that DND's actual four year average inventory, represented by the top of the maroon bar, widely exceeds the 99% fill rate optimal average inventory represented by the green region in each bar. The average inventory across these 17 items have inventory levels at least a factor of three greater than what we would expect from a simple (Q,r) policy. Collectively, at 6% interest the 17 items constitutes \$5.2M in holding costs. The optimal policy, with a 99% fill rate and an ordering cost set at ten times the annual holding costs (yielding an expectation of one to five years between replenishment orders across the 17 items) has a holding cost of only \$1.3M. We see that the high inventory position on these 17 items costs DND nearly an extra \$4M per year under our assumptions.

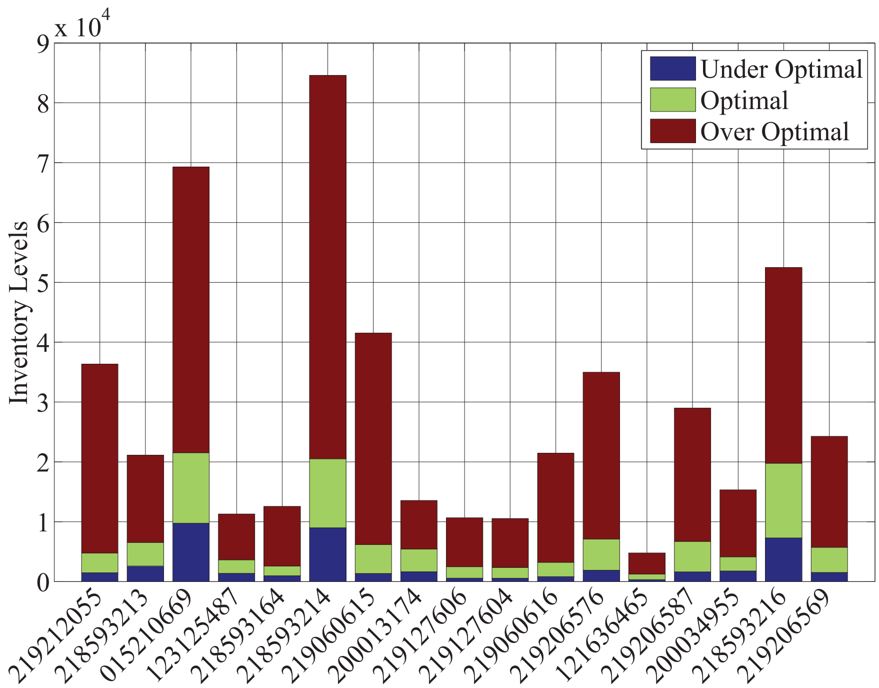

Figure 4: A4 Materiel Class Inventory flagged by the filter method. The green portion of each bar represents the range of the average inventory of all solutions along the optimal frontier with a 99% fill rate while the blue region of each bar gives an average inventory that fails to deliver a 99% fill rate. The top of the maroon bar represents DND's actual four year average inventory level.

While the extra inventory insulates against stock out with fill rates significantly above 99%, the insurance comes at a high cost. In discussions with technical authorities, we find the following issues lead to the high inventories:

- heavy reliance on forecasting of both demand, and internal budgets;
- reorder polices set by anticipation to avoid penalization associated with stock out;
- order schedule often set through long term contracts with suppliers (industrial support); and
- high use of discretion on reordering decisions.

Each of these points illustrates a departure from a more rules based approach, allowing for the possibility for inventory levels to move away from an optimal position. To move forward, DMGOR needs to interface with DRP champions and EPM personnel.

3 Conclusions

In this paper, we display the results of the filter method we developed to flag potentially problematic inventory in DND's holdings. By using a simple class of optimal inventory policies, namely (Q,r), we can identify which items have excessive inventory levels. Our application of this model to the current A4 Materiel Class data, which represent the highest value, fastest moving items in inventory, identifies 17 items out of 136 which have inventory levels significantly above (by at least a factor of three) an optimal (Q,r) policy with a 99% fill rate.

We emphasize that our filter methods only identify potentially problematic inventory for further study. Each item has its own unique inventory environment – from DND-wide network material flow issues to contract/manufacturing ordering requirements – which can have large effects on inventory levels. Nevertheless, the departure threshold that we set from the optimal policy represents a serious flag for consideration. We find it difficult to understand or rationalize a four-year average inventory level above the maximum possible (Q,r) inventory position with a 99% fill rate from the observed usage pattern and costing data alone. We stress that we have only scratched the surface in this problem area. The 99% fill rate that we use has no basis in operational requirements as we did not have requirement information during the study. With lead times on most items typically on the order of three months, a 99% lead time implies an average stock out rate of once every 25 years, which we felt set a adequate benchmark for flagging inventory. Conceivably, for some items a fill rate of 99% may be insufficient, but we can only address these issues with a more in depth study involving DGMSSC staff.

Our results call for more detailed DMGOR study, and a mandate to work closely with DRP champions, EPM personnel, and DGMSSC staff. Once our filter method identifies an item or set of items for potential excess inventory holdings, we require a further understanding of the underlying issues. Higher fidelity modelling, contractor lead time uncertainty, network and staging effects, and supplier relations represent the next layers in the study. We can only accomplish this goal with a clear mandate to integrate our study with DGMSSC.

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List of Acronyms

ADM(Mat)	Assistant Deputy Minister (Materiel)
CORA	Centre for Operational Research and Analysis
DRMIS	Defence Resource Management Information System
DRP	Distribution Resource Planning
EPM	Equipment Program Manager
DCOS(Mat)	Deputy Chief of Staff (Materiel)
DGMSSC	Director General Materiel Systems and Supply Chain
DMGOR	Directorate Materiel Group Operational Research
DND	Department of National Defence
DRDC	Defence Research and Development Canada
JIT	Just-in-Time
MRP	Material Resource Planning

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We apply a filter method, based on continuous review (Q, r) inventory policies, to the Department of National Defence's highest value and fastest moving inventory. The filter flags potentially problematic inventory levels in DND's holdings. Our results provide DND with a method that carefully targets the most problematic inventory issues, both in cost and total affected part numbers, for further study and examination. We apply our methods to the current A4 Material Class data, and we identify 17 out of 136 items which have inventory levels at least a factor of three above an optimal (Q, r) policy with a 99% fill rate. Our results call for more detailed Directorate Materiel Group Operational Research study and a mandate to work closely with Director General Materiel Systems and Supply Chain staff on inventory rationalization.

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Inventory control
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