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Effect of Supply Chain Finance Solutions on Production Planning Under Yield and Lead Time Uncertainty

Orkun Bayram [1]

Abstract

For capital constrained suppliers, use of supply chain finance requires consideration of interplay between production and finance decisions. We solve the optimal input procurement problem for a capital constrained make to order manufacturer subject to yield and lead time uncertainty and compare use of supply chain finance methods (Advance Payment Discount (APD), Bank Loan (BL), Reverse Factoring with initial bank loan (RF), and Buyer Backed Purchase Order Finance (BPOF)). Our model applies to manufacturing from raw material such as mechanical and electronics and service processes such as cold chain transportation with individual cooling units, e.g. for vaccine distribution. We model our problem via stochastic optimization with binomial production yield and discrete random lead time. We prove the convexity of the objective functions for APD, BL, and RF; and we show that the objective function for BPOF can be expressed as difference of two convex functions and employ Difference of Convex Functions programming to find the optimal production input amount. We see that, as frequently applied in practice, payment terms longer than 90 days may make the supplier give up on the order due to no expectation for any profit. Optimal profit is more sensitive than procurement amounts to the joint effect of interest rates and yield probability as well as fluctuations in lead time. For suppliers with higher yield rates BPOF brings the most advantage when interest rates are the same for all methods, and APD brings the most advantage when flexibility on interest rates it provides is employed for suppliers with lower yield rates. Methodologically, we develop an analytical make-to-order model under yield and lead time uncertainty and solve the resulting optimization problems using expected profit maximization, including DC programming for the BPOF scheme.

Keywords: Production Planning, Supply Chain Finance, Uncertain Yield, Uncertain Lead Time, Make to Order, Batch Production

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Tedarik Zinciri Finansmanı Çözümlerinin Verim ve Teslimat Süresi Belirsizliği Altında Ürün Planlamasına Etkisi

Orkun Bayram [1]

Öz

Sermaye kısıtı altında faaliyet gösteren tedarikçiler için tedarik zinciri finansmanının kullanımı, üretim ve finansman kararları arasındaki etkileşimin dikkate alınmasını gerektirmektedir. Bu çalışmada, verim (yield) ve teslim süresi belirsizliği altında, siparişe göre üretim yapan sermaye kısıtlı bir üretici için optimal girdi tedariki problemi çözülmekte ve farklı tedarik zinciri finansmanı yöntemlerinin kullanımı karşılaştırılmaktadır (Peşin Ödeme İskontosu – Advance Payment Discount (APD), Banka Kredisi – Bank Loan (BL), başlangıç banka kredisi içeren Ters Faktoring – Reverse Factoring (RF) ve Alıcı Destekli Satın Alma Emri Finansmanı – Buyer Backed Purchase Order Finance (BPOF)). Önerilen model; mekanik ve elektronik gibi hammaddeden üretim yapılan imalat süreçlerinin yanı sıra, örneğin aşı dağıtımı için bireysel soğutma ünitelerine sahip soğuk zincir taşımacılığı gibi hizmet süreçlerine de uygulanabilir niteliktedir. Problem, binom dağılımlı üretim verimi ve ayrık rassal teslim süresi varsayımları altında stokastik optimizasyon yoluyla modellenmiştir. APD, BL ve RF yöntemleri için amaç fonksiyonlarının konveks olduğu ispatlanmış; BPOF yöntemi için amaç fonksiyonunun iki konveks fonksiyonun farkı biçiminde ifade edilebildiği gösterilmiş ve optimal üretim girdisi miktarını belirlemek amacıyla Konveks Fonksiyonların Farkı (Difference of Convex Functions – DC) programlama yaklaşımı kullanılmıştır. Sonuçlar, uygulamada sıklıkla karşılaşıldığı üzere, 90 günden uzun ödeme vadelerinin tedarikçilerin herhangi bir kâr beklentisi kalmaması nedeniyle siparişten vazgeçmelerine yol açabileceğini göstermektedir. Optimal kârın, tedarik miktarlarına kıyasla, faiz oranları ile üretim verimi olasılığının ve teslim süresindeki dalgalanmaların ortak etkisine daha duyarlı olduğu görülmektedir. Daha yüksek verim oranlarına sahip tedarikçiler için, tüm yöntemlerde faiz oranlarının aynı olması durumunda BPOF en fazla avantajı sağlarken; daha düşük verim oranlarına sahip tedarikçiler açısından, sunduğu faiz oranı esnekliği kullanıldığında APD yöntemi en avantajlı seçenek olmaktadır. Çalışmada problem, binom verim ve ayrık rassal teslim süresi içeren bir stokastik optimizasyon modeli olarak formüle edilmiş ve her bir finansman yöntemi için optimal girdi miktarı, konvekslik sonuçları ve DC programlama kullanılarak elde edilmiştir.

Anahtar Kelimeler: Üretim Planlama, Tedarik Zinciri Finansmanı, Belirsiz Verim, Belirsiz Teslim Süresi, Sipariş Üzerine Üretim, Parti Üretimi

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Introductio

Financial distress caused by Covid19 exacerbated the financial troubles experienced by capital constrained suppliers. These suppliers had already been pressured by the extended payment terms introduced after 2008 financial meltdown, and with the pandemic crisis their need for working capital has become even more dire (Caniato, Moretto & Rice, 2020, p. 2). To satisfy the need for working capital, a prominent and increasingly more prevalent approach is Supply Chain Finance (SCF) (Ledger Insights, 2020, p. 537). While SCF could help capital constrained suppliers, its effectiveness depend on external and internal factors such as initial working capital level of the supplier, interest rates, and payment terms. In addition to these financial factors, other phenomena affecting the level of benefit received from SCF are the operational conditions of the supplier (e.g. production yield, Ding & Wan, 2020, p. 4). Based on the operational conditions of the supplier and internal and external factors mentioned above, the benefits from SCF can be maximized (Vliet, Reindorp & Fransoo, 2013, p. 12). To achieve this, the interplay of SCF and operational decisions has to be thoroughly analyzed. In this paper we focus on this analysis, particularly on the analysis of effects of SCF solutions on production planning for a capital constrained make to order manufacturer subject to yield and lead time uncertainty.

Yield uncertainty is likely to be sensed more due to localization approaches after Covid19 (Ivanov & Das, 2020, p. 97). The localization approach will include new and potentially capital constrained suppliers to supply chains; and for these suppliers consequences of yield loss on costs could be even more emphasized. Moreover, yield uncertainty is inherent in many industries such as high tech and food (Lowe, Khademi, & Mason, 2016, p. 2702; van Donk, 2001, p. 302), so it is inevitable to consider it for production planning decisions. Yield uncertainty for a make to order manufacturer working on contract basis is considered in our model since we believe localization in redesigned supply chains would lead to having multiple suppliers for contingencies; therefore, it will be more likely that the suppliers will work on contract basis. Moreover, contractbased production is known to be more efficient in industries with high product variety (Gupta, D., & Benjaafar, S., 2004, p. 538), so we consider production planning decisions for a single order satisfied by a make to order manufacturer.

Many different factors inherent in make to order production settings cause lead time uncertainty and lead time uncertainty causes fluctuations in timing of shipments. The uncertainty in timing of shipments further causes uncertainty in timing of invoice approvals, which leads to uncertainty in timing of payment settlements when SCF solutions are applied. Such fluctuations in timings of cash flows may influence manufacturer’s profit and production planning decisions. Therefore, lead time uncertainty is also an important random factor needing detailed consideration in interplay of SCF and operational decisions.

To account for yield and lead time uncertainty in analyzing the effect of SCF solutions on production planning decisions and profit of the manufacturer, we use binomial yield model to emphasize the yield’s dependence on individual input based factors such as raw material (Dettenbach, 2015, p. 86) and model total lead time from order confirmation to shipment and invoice approval with discrete and bounded distribution.

Besides manufacturing settings, service providers could also benefit from SCF solutions. For instance, transportation services are subject to uncertain yield (due to damage during transportation) and uncertain lead time. Special transport boxes as individual cold chain units with dry ice were designed to adhere to strict tempera ture requirements for Covid19 vaccines (Kleinman, 2020, p. 2). Thus, vaccine transportation process and also other transportation processes with individual cooling units subject to random transportation yield and time would also benefit from the analysis presented here.

We consider SCF solutions that are suitable to be used to support capital constrained suppliers by well capitalized buyers. We compare the prevalent preshipment method APD, very popular post shipment method RF applied in combination with initial bank loan, and to our knowledge, a comparably less analyzed preshipment method of BPOF (Wu, 2017, p. 5637; Huang, Wu & Chiang, 2018, p. 6078; Zhao & Huchzermeier, 2019, p.83). We also use the traditional bank loan (BL) as a benchmark. Via the analysis we conduct in this paper we aim to answer the research questions: 1) Can SCF improve operational decisions under uncontrollable factors affecting the production process? If so, to what extent? 2) Which SCF solution provides the highest improvement for a capital constrained supplier or which parameters could be used to control the effect of different SCF solutions on the operational decisions of a capital constrained supplier?

Our contributions are threefold: 1) We provide a thorough analysis of prevalent but so far less analyzed SCF solutions of APD and BPOF on their effect on production planning decisions and profit, and we further provide comparisons of benefits of these methods with the more frequently used post shipment method of RF and traditional BL; 2) We utilize Difference of Convex Functions (DC) programming method for analysis of production planning with BPOF. The analysis of this method required nonconvex programming, and we believe further analysis of this SCF method would again benefit from nonconvex optimization methods; thus, we present a novel optimization approach to further the analysis of BPOF method in literature; 3) To our knowledge, this is the first study to analyze the combined effect of uncertain production yield and lead time on the interplay of SCF and operational decisions. The interaction between financial and operational decisions are affected by both the timing and magnitude of financial flows; hence we demonstrate a clearer and detailed analysis of the extent of benefits gained from SCF with respect to both of these uncontrollable factors.

In the following sections, first we present the relevant literature and emphasize our contribution to it. The production planning models with different SCF solutions are presented in Section 3 followed by their solution algorithms in Section 4; afterwards, we further emphasize our findings with structural and numerical analysis in Section 5. Finally we end the paper with Conclusions.

1. **Literature Review**

Our study pertains to three main research streams: production and/or procurement with random yield, production planning and control with random lead time, and SCF.

1.1. Production and/or Procurement with Random Yield

Random yield in production and/or procurement has been studied for several decades regarding its effect on lot sizing decisions. Early literature could be reviewed on excellent works of (Yano & Lee, 1995, p. 327) and (GrosfeldNir & Gerchak, 2004, p. 57). For yield uncertainty, three main approaches in modelling are considered: stochastically proportional, interrupted geometric, and binomial. In our study we assume binomial yield and aim to minimize net negative of the profit. Our objective leads to finding the profit maximizing production input quantity. Hence, our context relates strongly to the standard approaches in lot sizing for random yield environments, but to further the literature in this context, we introduce the perspective of random lead time and enhance the research question by introducing SCF methods to analyze the effects of these methods on the lot sizing decision.

Our research problem involves make to order production decisions where production is made for a single order which may not be entirely satisfied if the random production yield results in an insufficient amount of non defective goods. Make to order environments with binomial production yield stayed as one of the main contexts to consider the effect of random production yield on lot sizing decisions, and characteristics of the production environments analysed in studies of make to order lot sizing with binomial yield varied from multistage produc tion with semiprocessed product procurement and rework decisions (Barad & Braha, 1996, p. 105) to multiproduct, multistage production and semifinished product allocation decisions (Talay & OzdemirAkyildirim, 2019, p. 547).

Another related production environment with binomial yield has been the newsvendor modeloriented studies with fixed demand and underage possibility similar to our case (Choi, Jeon, Kim & Park, 2019, p. 988). The analysis of production decisions under binomial yield uncertainty from the perspective of supply chain coordination and strategies for different supply chain partners has also been conducted (Clemens & Inderfurth, 2015, p. 319; Levi, Singhvi & Zheng, 2020, p. 217). As stated above, we enhance both the production environment context of the previous studies with explicit consideration of random lead time and the focus of the research question by considering and comparing the effects of different SCF methods on the lot sizing decision.

1.2. Production Planning and Control with Random Lead Time

Besides the random yield context, production and inventory control decisions with random lead time have been frequently analysed. Initial studies considered inventory control policies such as (R,Q) and specification of demand during lead time. Especially when both demand and lead time is random, the calculation of this quantity not only affected production amounts but also critical quantities such as safety stock (Eppen & Martin, 1988, p. 1384).

These effects had to be taken into consideration among different supply chain echelons including suppliers, producers, and distributors (Cohen & Lee, 1988, p. 223). One of the common approaches to model the batch production lead time was to assume a discrete probability distribution and measure the time in periods or discrete units. Either this distribution was to be estimated from historical data or discrete approximations for continuous lead time distributions were developed to model demand during lead time (Cobb, 2013, p. 224).

Assumption of given inventory control policies in lot sizing was not relevant to apply for make to order production and similar environments with random lead time; and later studies in this field started to focus on lot sizing and lead time planning based on due dates. With a given due date, even if the lead time was constant, if the production of a batch would not finish before the production of the next batch starts, lot sizing decisions became nontrivial with random yield (Wang & Gerchak, 2000, p. 381). Other random factors than yield, such as random supply disruptions, were also considered along with random lead time (Hekimoglu, van der Laan & Romme, 2018, p. 917). For lot sizing with lead time problems, especially in the case of multiple products, lot size for each product determined the production schedule as well. The lead time was assumed to be composed of deterministic (e. g. set up and processing) and random (e. g. waiting time in the queue) components and the production was done to satisfy a given demand (Kang, Albey & Uzsoy, 2018, p. 59; Rabta & Reiner, 2012, p. 2727). If multiple components were used to assemble a final product, then lead times for each component comprised the lead time for the final product (OuldLouly & Dolgui, 2004, p. 372). These studies also frequently included random and bounded lead time with a discrete distribution, since it was argued that in practice time is measured in periods and empirical distributions could be estimated based on historical data.

With the advances in electronics industry and other competitive sectors with quick obsoletion of products, both uncertain yield and timely component production and assembly of final products became the focus of production policies, e. g. in semiconductor manufacturing. In such industries, the production is subject to both random yield and random lead time, and production lot sizing and sequencing should be simultaneously considered. This is because the order of production would also affect the total lead time due to different set up times based on which component would be produced following which one. The common convention of assuming the random lead time to be composed of a deterministic and a random component was also followed in these studies. A decomposition approach to reduce the complexity of the solution algorithm was proposed to distinguish the lot sizing and sequencing optimization problems and different solution methodologies were evaluated (Schemeleva, Delorme & Dolgui, 2018, p. 186).

While the literature on production and inventory control decisions considered production environments ex posed to random yield and random lead time, to our knowledge, none of the studies considered both of these uncontrollable factors simultaneously for the interplay of operational and financial decisions. With the antici pated tendency to reshore and setup local suppliers and working capital crises experienced by suppliers in many supply chains, we believe any interplay of operational and financial policies would benefit greatly from explicit treatment of random yield and random lead time.

Random yield would be an undeniable occurrence in setting up new local suppliers with possible underage costs, and random lead times would affect the timing of cash flows because in many SCF methods, the settlements of payments would occur based on the time of shipment and invoice approval. Thus, both the magnitude and timing of cash flows for such suppliers will be affected by these uncontrollable factors; and the interaction between operational and financial policies needs to be analyzed with explicit consideration of these factors. To fill this gap in the literature, we present, to our knowledge, the first treatment of interplay between production planning and SCF decisions to support a capital constrained supplier with random yield and lead time.

1.3. Supply Chain Finance

Our study considers comparison of potential SCF solutions to be provided to a capital constrained supplier that use the better credit rating and/or cash availability of a well capitalized buyer. One of the SCF solutions that has gotten comparably little attention in theoretical studies is the BPOF where the purchase order is financed by a loan guaranteed by the buyer and taken from an external financial institution (Wu, 2017, p. 5641). The studies on this SCF solution involve how it affects the production input for a capital constrained supplier with stochastically proportional yield (Wu, 2017, p. 5640; Huang, Wu & Chiang, 2018, p. 6079); the loan amount could be determined by the buyer (Cao, Zhang & Ma, 2019, p. 119387) or loan guarantee could be provided partially. It has been noted in the literature that this SCF solution has not been thoroughly analysed yet. While analysis of BPOF on the production decisions have considered the random yield, to our knowledge, very few studies compared BPOF with the other preshipment SCF solutions, e. g. APD, where the buyer chooses to make an advance payment to the capital constrained supplier to initiate production. Moreover, we apply a novel analysis method to find the optimal production input amount for BPOF due to nonconvex nature of the net negative profit function. The credit guarantee applied in BPOF leads to a piecewise structure and we use difference of convex functions (DC) programming to optimize the production input amount. We believe our study also contributes to the literature methodologically by demonstrating a viable method of nonconvex optimization to apply for theoretical analysis of BPOF and other SCF solutions.

The rare studies on the comparison of preshipment SCF solutions so far focused on demand and asset variabilities based on financial markets (Zhao & Huchzermeier, 2019, p. 87; Wu, Wang, Xu & Chen, 2019, p. 252). Our study makes a comparison of preshipment SCF finance solutions from the perspective of the capital constrained supplier's production planning policy; the supplier works on contract basis and hence produces on make to order basis. In our setting demand is fixed by the order amount to be satisfied, the production is made in batches and subject to random yield and lead time. We further compare these SCF solutions with the widelyused post shipment SCF solution, RF).

RF could arguably be accepted as the most widely used SCF solution (Camerinelli, 2014), and it lets the supplier settle the payment earlier than the payment terms after the invoice is approved by the buyer. In fact, the supplier's earlier payment is made via a loan provided to the buyer by a financial institution. The buyer pays back the loan at the original settlement date, and that date is determined at the time of the contract, which usually leads to a payment terms extension compared to the case with no RF used (Gruter & Wuttke, 2017, p. 6617). Early payment to the supplier and payment terms extension for the buyer allows both to improve their working capital management, so RF is one of the most popular SCF solutions used. It is more widely analysed in the literature with random demand for make to order and make to stock production (Tanrisever, Cetinay, Reindorp & Fransoo, 2015, p. 18) and liquidity risks (Kouvelis & Xu, 2021, p. 6079). To our knowledge, this is one of the first studies to compare the effect of preshipment (APD and BPOF) and post shipment (RF) SCF solutions on the production planning policy of a capital constrained supplier and elaborate on how different parameters for each SCF solution could be arranged to affect the production input amounts for the supplier subject to random yield and random lead time.

Previously, the generic and holistic modelling approaches has been examined to jointly optimize financial and operational flows (Pfohl & Gomm, 2009, p. 157), and we observe an increasing acknowledgement of potential improvements brought by SCF to the production input amount for a supplier with random yield. Since an increase in the production amount could decrease potential shortages in the delivered amount, it will increase the reliability of the supplier and smoothen the operational flows within the supply chain. Examples of these recent studies consider supply chain coordination with capital constrained suppliers subject to random yield, with fixed demand and APD as the SCF solution (Ding & Wan, 2020, p. 7) or with dualsourcing options available to the buyer subject to demand volatility (Yuan, Bi & Liu, 2020, p. 301). We believe, for many applications, the production completion and hence shipment and invoice approval times are uncertain because of random lead times, and this uncertainty would inevitably affect the payment settlement time. In this case, different SCF solutions may have different effects on the production input amount even when the interest rates and payment terms applied are the same. These potential effects could not be observed and analysed without acknowledgement of lead time uncertainty, and our research aims to fill this gap in the literature as another contribution.

2. Model

In this section, we will describe model formulations for production planning of a capital constrained make to order manufacturer subject to random production yield and lead time where his/her working capital needs are satisfied via one of APD, bank loan (BL), combination of preshipment bank loan and RF, and BPOF. The manufacturer must plan for production of a single order with the amount N. Each input is transformed into one finished product, and common to make to order production, all inputs will be processed as a single batch (see e.g. Barad & Braha, 1996; GrosfeldNir & Gerchak, 2004; Iva˘nescu, Fransoo & Bertrand, 2006; Sharda & Akiya, 2012; Wang & Gerchak, 2000).

The production process involves yield and lead time uncertainties. For each input the process of obtaining a usable product follows a Bernoulli type with probability, p, and hence for an input amount of (X), the total amount of nondefective products obtained from the batch will be a binomial random variable, Bin(X, p). Binomial production yield is one of the main representations of production yield (Yano & Lee, 1995, p. 330) and has been used for modeling production defects caused by individual characteristics of inputs such as faulty raw material (Talay & Ozdemir Akyıldırım, 2019, p. 550) and/or production processes where individual units will be subject to independent and identical yield (Clemens & Inderfurth, 2015, p. 323), ranging from microfluidic chip manufacturing (Choi, Jeon, Kim, & Park, 2019, p. 990) to farming (Levi, Singhvi, & Zheng, 2020, p. 223).

Due to uncertain production yield, the amount of nondefective outputs obtained from a batch of (X) inputs could be smaller than the input amount; therefore, the manufacturer should determine the production amount to be no smaller than the order amount ($X \geq N$). If the order amount cannot be satisfied fully, a penalty cost (cpe) will be incurred for each unit of nondelivered item. Thus, for each unit of nondelivered item, not only the unit price P will be forfeited, but also the penalty cost (cpe) will be incurred. Hence, the underage cost for each nondelivered item will be (P + cpe). Under these conditions, the manufacturer must decide on the input amount (X) for a make to order production of a single batch. Without loss of generality, we normalize the salvage value to zero.

We model the lead time to be consisting of two elements: (1) a constant setup and processing time for the batch that depends on the performance and technical capabilities of production equipment, TM, and (2) a random time period, TE , caused by factors such as delays due to production of other orders or machine breakdown and maintenance. In the production planning/scheduling literature, the batch production lead time generally includes a deterministic component for setup (see, e. g. Cohen & Lee, 1988, p. 226; Kang, Albey & Uzsoy, 2018, p. 63; Rabta & Reiner, 2012, p. 2724); and a random time interval for production and/or delays due to breakdowns or other unexpected external causes (Kang, Albey & Uzsoy, 2018, p. 55; Schemeleva, Delorme, & Dolgui, 2018, p. 190).

Discrete lead times have been used to model various production planning and management settings. For instance, periodic review require discrete lead time distributions (Eppen & Martin, 1988 p. 1389; Hekimoglu, van der Laan & Dekker, 2018, p. 920), and lower and upper bounds are also assumed to characterize discrete lead times (Ould Louly & Dolgui, 2004, p. 374; Turkcan, Akturk & Storer, 2009, p. 1087). Methods to convert continuous distributions to discrete ones have also been proposed (Ganeshan, Tyworth & Guo, 1999, p. 18; Cobb, 2013, p. 226). Similar to the previous literature, we discretize the time units without restricting the choice of the time unit; therefore, the following time periods to express the lead time will be discrete quantities: the setup and processing time for the batch, TM, and the random time period happening from external factors not related with the production input decision or production yield of that particular order, TE ∈ {0, ...,UE }. Hence, we express the lead time, LT , via a discrete distribution with a lower and upper bound, LT ∈ {TM, . . . , TM + UE }, and suggest the use of conversion to discrete distribution previously adopted in the literature if required. We do not pose any restrictions on the form of the lead time distribution which allows for the use of estimated distributions from historical data (Eppen & Martin, 1988,p. 1387).

The manufacturer must also consider internal cost parameters and external financial parameters in determin ing the input amount (X). The manufacturer incurs a setup cost, K, and a unit production cost, c. The per unit time risk free interest rate is denoted with r f . All interest rates are taken as per unit time values; this way, it is possible to compare the relationship between the working capital costs and random lead time. It is assumed that the manufacturer has an insufficient amount of initial capital, A, as well. The notation is summarized in Table 1.

Table 1. Notation

Parameters	
N	order amount to be satisfied
p	probability of producing a non-defective item
c^{pe}	unit penalty cost to be incurred for each unit of non-delivered item
P	unit price for the product
T^M	setup and processing time for the batch
T^E	random time period due to external factors
U^E	upper bound for T^E
LT	lead time until shipment and invoice approval, $LT = T^M + T^E$
T^P_{APD}	payment term for APD, time period btw shipment and invoice approval and payment settlement
T^P_{BL}	payment term for BL
T^D_{BL}	deadline for the payment of the bank loan
K	setup cost for production
c	unit production cost
r^f	unit period risk-free interest rate
r^{APD}	unit period interest rate for APD
$r_1^{BL(S)}$	unit period interest rate applied by the bank based on the manufacturer's credit rating
$r_2^{BL(S)}$	unit period interest rate applied by the bank to the manufacturer if the loan deadline is exceeded
A	initial capital amount of the manufacturer
T^P_{RF}	payment term for RF
T^D_{RF}	deadline for the payment of the initial bank loan to start the production in case RF is applied
r^{RF}	unit period discounting rate for early payment if RF is applied
T^P_{BPOF}	payment term for BPOF
T^D_{BPOF}	deadline for the payment of the bank loan guaranteed by the buyer

APD: If the working capital needs of the manufacturer are to be satisfied with this SCF method, then, the buyer will provide the rest of the costs for the production. At the time of payment settlement, which will be after TP time units following shipment and invoice approval, s/he will apply a higher interest rate, rAPD, than the riskfree rate to this compensation and deduct it from the payment amount for the order, PN. The timing and sequence of cash flows for a production input amount, X , can be summarized as below.

Time 0: The buyer lends the manufacturer K + cX − A. The manufacturer spends the initial capital s/he has,

A, plus the amount lent by the buyer to start the production.

Time TM + TE: The order is shipped and confirmed.

Time TM + TE + TP : Payment is settled; the manufacturer's revenue is PN, his/her underage cost is $(\boldsymbol{P} + \boldsymbol{cpe})[\boldsymbol{N} - \boldsymbol{Bin}(\boldsymbol{X},\boldsymbol{p})]+,$ ***and his working capital cost is*** $(\boldsymbol{K} + \boldsymbol{cX} - \boldsymbol{A})(\boldsymbol{1} + \boldsymbol{rAPD})(\boldsymbol{TM} + \boldsymbol{TE} + \boldsymbol{TP})$.

The production input amount that maximizes the manufacturer's profit can be expressed as the amount min imizing the negative of the manufacturer's net profit. To compare different SCF methods, we will consider the net present value (NPV) of the negative of the manufacturer's net profit; and we assume the manufacturer is riskneutral and rational, so we will focus on expected value minimization. Thus, the objective function for the manufacturer's production planning problem for APD can be expressed as below (Z∗ denotes the set of nonnegative integers):

$$\begin{aligned}
&\mathbf{min}_X \boldsymbol{\Pi}\big(\boldsymbol{APD}(\boldsymbol{X})\big)\\
&= \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{r^f})^{T^M+T^p_{APD}}} \boldsymbol{E}_{T^E}\left[\frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{r^f})^{T^E}}\right] \boldsymbol{E}_{\mathrm{Bin}(X,p)}[(\boldsymbol{P}+\boldsymbol{c^{pe}})[\boldsymbol{N}-\mathbf{Bin}(\boldsymbol{X},\boldsymbol{p})]^+ - \boldsymbol{PN}] + \boldsymbol{A}\\
&+(\boldsymbol{K}+\boldsymbol{cX}-\boldsymbol{A})\left(\frac{\mathbf{1}+\boldsymbol{r^{APD}}}{\mathbf{1}+\boldsymbol{r^f}}\right)^{T^M+T^p_{APD}} \boldsymbol{E}_{T^E}\left[\left(\frac{\mathbf{1}+\boldsymbol{r^{APD}}}{\mathbf{1}+\boldsymbol{r^f}}\right)^{T^E}\right] \qquad (\mathbf{1})\\
&\text{s.t. } \boldsymbol{X} \geq \boldsymbol{N}, \boldsymbol{X} \in \mathbb{Z}^*
\end{aligned}$$

Bank Loan (BL): If the working capital needs of the manufacturer are to be satisfied via BL, the manufacturer will borrow a bank loan to be paid on a deadline, TD , with interest rate determined based on the manufacturer's own credit rating, which we will denote with rBL(S) since the manufacturer is the seller. The payment settlement with the buyer will be made after TP time units following shipment and invoice approval. In case the deadline is exceeded, the bank will start charging a higher interest rate, $rBL(S)_2$, ($rBL(S)_2$ > $rBL(S)_1$). The timing and sequence of cash flows for a production input amount, X , can be summarized as below.

Time 0: The bank lends the manufacturer K + cX − A. The manufacturer spends the initial capital s/he has, A, plus the amount lent by the bank to start the production. Time T^M + T^E: The order is shipped and confirmed. APD, the objective function represents the expected NPV of negative of net profit for the manufacturer.

$$\begin{aligned}
&\min_{X} \boldsymbol{\Pi}(\boldsymbol{BL}(\boldsymbol{X}))\\
&= \frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{r}^{f})^{\boldsymbol{T}^{M}+\boldsymbol{T}^{p}_{BL}}} \boldsymbol{E}_{\boldsymbol{T}^{E}}\left[\frac{\mathbf{1}}{(\mathbf{1}+\boldsymbol{r}^{f})^{\boldsymbol{T}^{E}}}\right] \boldsymbol{E}_{\boldsymbol{Bin}(\boldsymbol{X},\boldsymbol{p})}[(\boldsymbol{P}+\boldsymbol{c}^{pe})[\boldsymbol{N}-\boldsymbol{Bin}(\boldsymbol{X},\boldsymbol{p})]^{+}-\boldsymbol{PN}]+\boldsymbol{A}\\
&+(\boldsymbol{K}+\boldsymbol{cX}-\boldsymbol{A})\left\{\left(\frac{\mathbf{1}+\boldsymbol{r}_{1}^{BL(S)}}{\mathbf{1}+\boldsymbol{r}^{f}}\right)^{\boldsymbol{T}^{M}+\boldsymbol{T}^{p}_{BL}} \sum_{\boldsymbol{T}^{E}\leq \boldsymbol{T}^{D}_{BL}-(\boldsymbol{T}^{M}+\boldsymbol{T}^{p}_{BL})} \left(\frac{\mathbf{1}+\boldsymbol{r}_{1}^{BL(S)}}{\mathbf{1}+\boldsymbol{r}^{f}}\right)^{\boldsymbol{i}} \boldsymbol{P}(\boldsymbol{T}^{E}=\boldsymbol{i}) \right. \quad (\mathbf{2})\\
&\left. +\left(\frac{\mathbf{1}+\boldsymbol{r}_{2}^{BL(S)}}{\mathbf{1}+\boldsymbol{r}^{f}}\right)^{\boldsymbol{T}^{M}+\boldsymbol{T}^{p}_{BL}} \left(\frac{\mathbf{1}+\boldsymbol{r}_{1}^{BL(S)}}{\mathbf{1}+\boldsymbol{r}_{2}^{BL(S)}}\right) \sum_{\boldsymbol{T}^{E}> \boldsymbol{T}^{D}_{BL}-(\boldsymbol{T}^{M}+\boldsymbol{T}^{p}_{BL})} \left(\frac{\mathbf{1}+\boldsymbol{r}_{2}^{BL(S)}}{\mathbf{1}+\boldsymbol{r}^{f}}\right)^{\boldsymbol{i}} \boldsymbol{P}(\boldsymbol{T}^{E}=\boldsymbol{i})\right\}\\
&\text{s.t. } \boldsymbol{X}\geq \boldsymbol{N}, \boldsymbol{X}\in \mathbb{Z}^{*}.
\end{aligned}$$

Preshipment Bank Loan and RF: If this method is chosen by the buyer to offer to the manufacturer for his/her working capital needs, the manufacturer will be able to obtain the payment directly following shipment and invoice approval, after a discount rate, rRF (based on the buyer's credit rating) is applied. Hence, the payment term, TP , will be skipped.

If underage costs are low enough, coupled with early payment, this will allow the manufacturer to be able to pay the bank loan earlier compared to other methods and hence incur a lower total amount of interest applied to the principal. The bank loan will have the due date, TD , and the interest rate on the initial loan will be based on the manufacturer's own credit rating as in BL method, rBL(S). Similar to the case with BL, a higher interest rate will be charged per unit time (rBL(S)) if the loan deadline is exceeded. Since the manufacturer is capital constrained, the earlier payment will also help him/her with forthcoming production costs regarding future orders, so we will assume complete factoring of the payment will be executed. The timing and sequence of cash flows for a production input amount, X , can be summarized as below.

Time 0: The bank lends the manufacturer K + cX − A. The manufacturer spends the initial capital s/he has, A, plus the amount lent by the bank to start the production.

Time T^M + T^E: The order is shipped and invoice is approved; the payment is discounted and settled, so the financial institution will pay (PN − (P + cpe)[N − Bin(X, p)]+)/(1 + rRF)TP to the manufacturer on behalf of the buyer. The manufacturer will incur working capital cost (K + cX − A)(1 + rBL(S))(TM +TE) if the deadline is not exceeded and (K + cX − A)(1 + r^{BLS_1})$T^D{}_{RF}$ (1 + r^{BLS_2})$(^{TM+TETD})_{RF}$ if the deadline is exceeded. As before, the objective function represents the expected NPV of negative of net profit for the manufacturer.

$$\min_{X}\Pi\big(RF(X)\big) = \frac{1}{(1+r^{\dagger}\setminus T^{M}}\frac{1}{(1+r^{RF})^{T_{RF}^{L}}E_{TE}}\frac{1}{T^{BL(S)}+r^{\dagger}\setminus T^{E}}\;E_{\mathrm{Bin}(Xp)}\big(P+c^{pe)}[N-\mathrm{Bin}(X,p)]^{+}-PN+A \tag{3}$$

$$\text{s.t. } X \geq N, X \in \mathbf{Z}^{*}.$$

BPOF: In this SCF method, the buyer provides credit guarantee to the bank for the loan taken by the seller (with a payback deadline, TD), and hence the bank agrees to process the loan based on the credit rating of the buyer. Thus, a lower interest rate, based on the buyer, rBL(B), will be applied to the loan. Similar to previous methods, a payment settlement time (TP) following the confirmation of shipment is applied here as well. The timing and sequence of cash flows for a production input amount, X , can be summarized as below.

Time 0: The bank lends the manufacturer K + cX − A. The manufacturer spends the initial capital s/he has, A, plus the amount lent by the bank to start the production.

Time TM + TE: The order is shipped and confirmed.

Time TM + TE + TP: If the due date of the loan, TD, is not exceeded, the buyer determines Revenue Underage Costs=(PN − (P + cpe)[N − Bin(X, p)]+). If (PN − (P + cpe)[N − Bin(X, p)]+) is positive, then the buyer further determines total profit (or loss if negative)=[(PN −(P + cpe)[N − Bin(X, p)]+) −(K + cX − A)(1 + rBL(B))TM +TE +TP]. If [(PN −(P + c)[N − Bin(X, p)]) −(K + cX − A)(1 + r)BPOF] is also positive, then the buyer pays (PN −(P + cpe)[N − Bin(X, p)]+) to the bank and the bank deducts [(K + cX − A)(1 + rBL(B))TM +TE +TP] from it, and pays the rest to the seller. If (PN − (P + cpe)[N − Bin(X, p)]+) is positive but [(PN − (P + cpe)[N − Bin(X, p)]+) − (K + cX − A)(1 + rBL(B))TM +TE +TP] is negative, then this means although the (RevenueUnderage Costs) from the order is positive, it was not enough to pay all of the loan principal and interest to the bank. Therefore, the buyer pays for the amount left of the loan principal and interest to the bank and the seller earns nothing, but had lost A that s/he has paid at the beginning only. If (PN −(P + cpe)[N − Bin(X, p)]+) is negative so that the underage cost is so high it cancels all the revenue, then the buyer pays the loan and the principal [(K + cX − A)(1 + rBL(B))TM +TE +TP] to the bank, and the manufacturer owes the buyer the negative of (PN −(P + cpe)[N − Bin(X, p)]+). The manufacturer loses both this amount and A s/he has paid at the beginning.

If the due date of the loan, TD, is exceeded, the buyer first pays the principal and interest back to the bank at the deadline in order to not incur any higher interest. Then, at the time of payment settlement, the buyer checks (PN −(P + cpe)[N − Bin(X, p)]+). If (PN −(P + cpe)[N − Bin(X, p)]+) is positive, then the buyer further checks [(PN −(P + cpe)[N − Bin(X, p)]+) −(K + cX − A)(1 + rBL(B))TD(1 + r)BPOF].

If [(PN −(P + cpe)[N − Bin(X, p)]+) −(K + cX − A)(1 + rBL(B))TD (1 + r) BPOFd] is also positive, then the buyer pays only this amount to the manufacturer. Otherwise, so that (PN − (P + cpe)[N −Bin(X, p)]+) is positive but [(PN −(P+cpe)[N −Bin(X, p)]+)−(K +cX −A)(1+rBL(B))TD (1+r)BPOF D] is negative, meaning that the manufacturer is making a loss no greater than the loan amount, the buyer keeps (PN −(P + cpe)[N −Bin(X, p)]+) (note that the loan is already paid due to deadline excess), and the manufacturer only ends up losing A s/he has paid at the beginning.

If the loan deadline is exceeded and (PN − (P + cpe)[N − Bin(X, p)]+) is negative, then the buyer holds the manufacturer responsible only for the negative of (PN −(P + cpe)[N − Bin(X, p)]+) and the loan is already paid, so the manufacturer loses only this amount and A s/he has paid at the beginning.

The objective function below represents the expected NPV of negative of net profit for the manufacturer.

$$
\begin{aligned}
&\min_{X}\Pi(BPOF(X))\\
&= \sum_{T^E \leq T^D_{BPOF}-(T^M+T^P_{BPOF})} \left[\frac{1}{(1+r^f)^{T^M+T^P_{BPOF}+i}}\right] P(T^E=i)\\
&.\,E_{Bin(X,p)}\left[\min\left(\left[(P+c^{pe})[N-Bin(X,p)]^+ + (K+cX-A)\left(1+r^{BL(B)}\right)^{T^M+i+T^P_{BPOF}} - PN\right],0\right)\right]\\
&+ \sum_{T^E > T^D_{BPOF}-(T^M+T^P_{BPOF})} \left[\frac{1}{(1+r^f)^{T^M+T^P_{BPOF}+i}}\right] P(T^E=i)\\
&.\,E_{Bin(X,p)}\left[\min\left(\left[(P+c^{pe)})[N-Bin(X,p)]^+ + (K+cX-A)\left(1+r^{BL(B)}\right)^{T^D_{BPOF}(1+r^f)^{T^M+i+T^P_{BPOF}-T^D_{BPOF}}-PN}\right],0\right)\right]\\
&+E_{Bin}(X,p)[\max([(P+c^{pe})[N-Bin(X,p)]^+ - PN],0)] + A\\
&\text{s.t. } X \geq N, X \in \mathbb{Z}^*.
\end{aligned}
$$

3. Structural and Numerical Analysis

In this section we will elaborate on how different SCF methods affect the production input amount and profit of the manufacturer. We will first provide an analytical comparison of the optimal input amounts for APD, BL, and RF methods and then further elaborate on these results via Numerical Analysis. Since optimal production input amount for BPOF method is found via DC programming methodology, it does not provide a direct threshold value for the underage probability of the production input amount. Thus, we provide its comparison with the other methods via our Numerical Analysis.

In this section we compare APD, BL, and RF methods with each other based on parameter values. Comparison of optimal input amounts (X ∗) for BL and RF: We will first restate the threshold values for BL and RF here by involving the multipliers within the summations in the numerators.

Thresholdvalue for BL:

$$
\frac{\boldsymbol{c}\left\{\displaystyle\sum_{T^E \leq T^D_{RL}-(T^M+T^P_{RL})} \left(\frac{1+r_1^{BL(S)}}{1+r^f}\right)^{T^M+T^p_{BL}+i} P(T^E=i) + \sum_{T^E > T^D_{BL}-(T^M+T^p_{BL})} \left(\frac{\left(1+r_1^{BL(S)}\right)^{T^D_{BL}\left(1+r_2^{BL(S)}\right)^{i-\left[T^D_{BL}-\left(T^M+T^p_{BL}\right)\right]}}}{(1+r^f)^{T^M+T^p_{BL}+i}}\right) P(T^E=i)\right\}}{\dfrac{1}{(1+r^f)^{T^M+T^P_{BL}}} E_{T^E}\left[\dfrac{1}{(1+r^f)^{T^E}}\right] p(P+c^{pe})}
\tag{4}
$$

Thresholdvalue for ***RF***:

$$
\boldsymbol{c}\left\{\sum_{T^E \leq T^D_{RF}-T^M} \left(\frac{1+r_1^{BL(S)}}{1+r^f}\right)^{T^M+i} P(T^E=i) + \sum_{T^E > T^D_{RF}-T^M} \left(\frac{\left(1+r_1^{BL(S)}\right)^{T^D_{RF}}\left(1+r_2^{BL(S)}\right)^{i-[T^D_{RF}-T^{Mf}]}}{(1+r^f)^{T^M+i}}\right) P(T^E=i)\right\}
\cdot \frac{1}{\dfrac{1}{(1+r^f)^{T^M}}\dfrac{1}{(1+r^{RF})^{T^D_{RF}}} E_{T^E}\left[\dfrac{1}{(1+r^f)^{T^E}}\right] p(P+c^{pe})}
$$

In the RF method, instead of waiting until the payment term T^{P}_{RF} ends to receive the payment, the manufacturer could get early payment with a discount. Hence, it is expected that T^{D}_{RF} depends on lead time only, e. g.

$T^{D}_{RF}= T^{M} + E[T^{E}]$, so the initial loan deadline is expected to be based only on production dynamics. Assuming this, we will make a comparison based on the suggestion, $T^{D} = T^{D} + T^{P}$.

3.1. **Numerical Analysis**

In this subsection, we solve our models to compare the four different supply chain financing options under different production yield and lead time parameters to obtain further insights into the comparisons presented above. Here we also include the comparison of the three financing options with the BPOF method, since this method involves a nonconvex objective function and is less tractable to structural analysis.

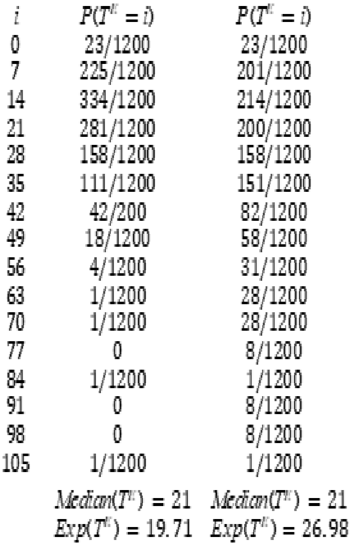
We take the parameter values used in our Numerical Analysis from the literature and other secondary data resources. For yield probabilities, p, we observe the range has been [0.70.9] in the literature (see e. g. Ben Zvi & GrosfeldNir, 2007, p. 242; Pentico, 1994, p. 2457); in addition, we extend the range to [0.50.9] since we believe the emerging trend of nearshoring after Covid crisis could bring lower yields for a considerable amount of time at the local manufacturers.

For the order amount, N, the previous examples included 10, 20, 30, 40, 50 (Pentico, 1994, p. 2459) or single amounts such as 40 (Barad & Braha, 1996, p. 109). We chose to use a single value of 30. We believe order amounts in tens could be more suitable for potential applications such as transportation yield in individual cooling units during vaccine distribution and customized make to order production (Fernandes & Ellram, 2017, p. 15). While our models do not restrict the time unit, for representation purposes we use days as the time unit here, and we have taken equal values of 30, 60 for external preshipment financing methods

(TP_{BL} , TP_{BFOF}). We let the payment terms for APD and RF, TP_{APD} , TP_{RF} , change from the same value as BL and BPOF up to 120 in increments of 30.

We set the price P to be 50 and the additional underage penalty cpe to be 10 as in (Talay & Ozdemir Akyildirim, 2019, p. 541); we take the set up cost K to be 10 and the unit production cost c to be 5. We assumed the manufacturer to have zero initial working capital (A) to start the production, which is plausible after the huge disruptions in many supply chains following Covid crisis, regardless of how well the company were doing before the crisis.

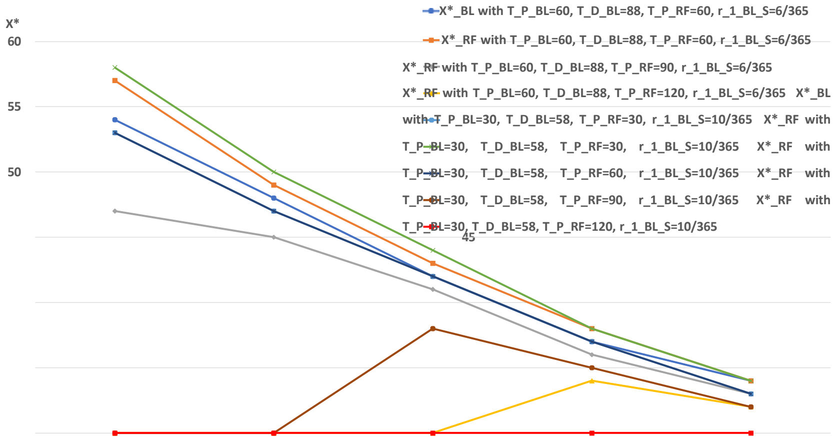
Table 2. Empirical Lead Time Distributions used in Numerical Analysis (Michna, Disney, & Nielsen, 2020:2)



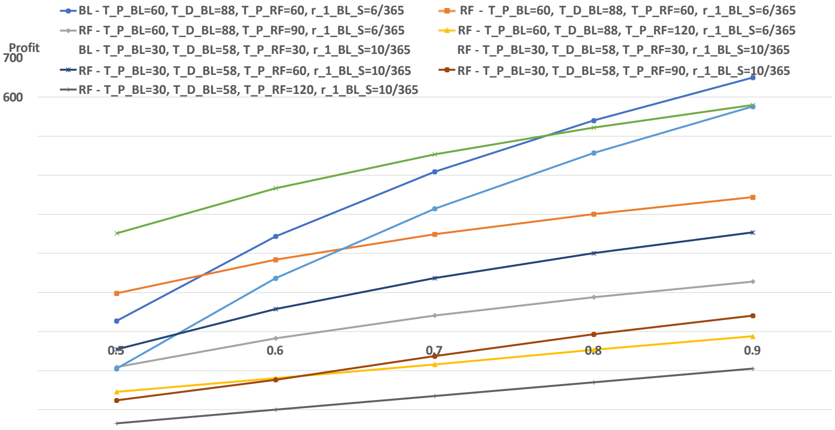
i	$P(T^{K} = i)$	$P(T^{K} = i)$
0	23/1200	23/1200
7	225/1200	201/1200
14	334/1200	214/1200
21	281/1200	200/1200
28	158/1200	158/1200
35	111/1200	151/1200
42	42/200	82/1200
49	18/1200	58/1200
56	4/1200	31/1200
63	1/1200	28/1200
70	1/1200	28/1200
77	0	8/1200
84	1/1200	1/1200
91	0	8/1200
98	0	8/1200
105	1/1200	1/1200
	$Median(T^{K}) = 21$	$Median(T^{K}) = 21$
	$Exp(T^{K}) = 19.71$	$Exp(T^{K}) = 26.98$

Comparison of optimal input amounts (X ∗) for BL and RF: For Figures 1 and 2 below, the following values are assumed thorough all the graphs: r f = 0.00016, TM = 7, P = 50, cpe = 10, K = 10, c = 5, N = 30, rBL(S) = 11/365, A = 0. Here the same riskfree interest rate (r f), price and penalty cost (P, cpe), and yield and lead time distributions as well as cost parameters are used to compare BL and RF methods. **Figure 1**. employs the 'Original Example' lead time distribution, whereas **Figure 2.** employs the 'Modified Version'. From Structural Analysis subsection above, we know that, under these conditions, the comparison of the optimal input amount (X ∗) and hence the optimal profit of the manufacturer for either method (Π(BL(X ∗)), Π(RF(X ∗))) would depend BL(S) TP on the ratio (1+r1) BL . In Figures 1 and 2, for rRF = 5/365 and rBL(S) = 6/365, TP was taken to be 60, (1+rP) RF1BL and TP ∈ {60, 90, 120}, which gave corresponding ratios of 1.176, 0.782, and 0.52, respectively. The graphs represent the trend of optimal production input and profit of the manufacturer as the production yield rises from 0.5 to 0.9, and as presented in the Structural Analysis subsection, only for TP_{RF} = 60 we had $X_{BL} \ast \geq X_{RF} \ast$, as T^{P}_{RF} became equal to or higher than 90, applying RF with initial bank loan to start production became disadvantageous for both the manufacturer and the buyer. The drop on the production amount was much more pronounced for lower yield rate values, and Π(RF(X ∗)) became negative for all yield (p) values for TP = 120, so the manufacturer would not even accept the contract with this payment term. A similar trend was observed for P = 30 and TP ∈ {30, 60, 90, 120}.

Overall, for the case where the lead time distribution has the mean and median values close to each other ('Original Example', Figures 1a and 1b), we see the drastic effect of the long payment terms for RF when the:

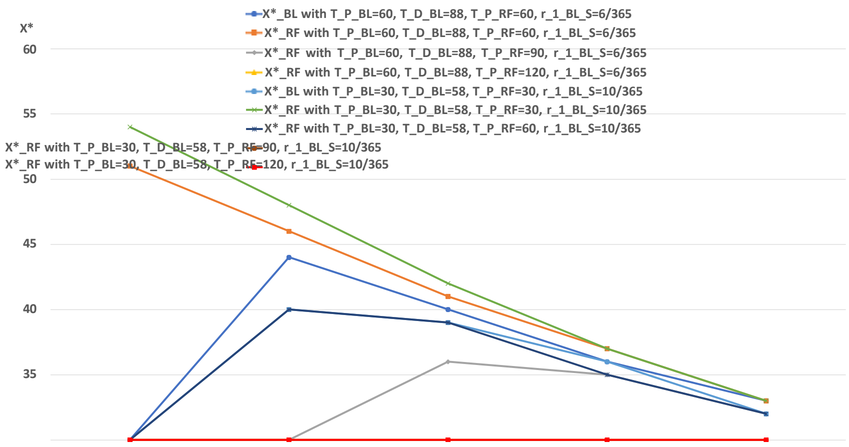


(a) BL and RF Comparison Optimal input (X ∗) w.r.t. Yield prob. (p) Lead Time 'Original Example' (initial loan deadline for RF, TD = 28, and early payment discounting rate for RF (based on the buyer's credit rating), rRF = 5/365)

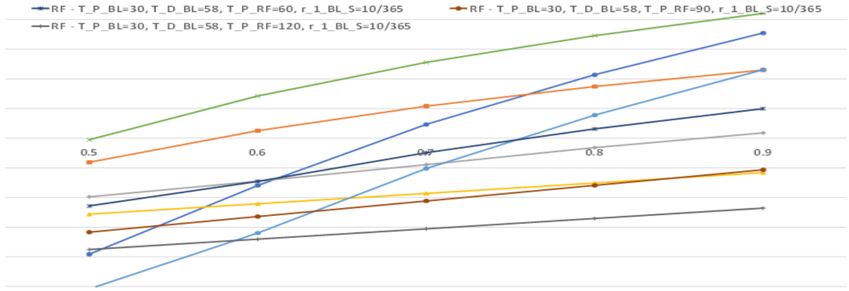


(b) BL and RF Comparison Optimal profit w.r.t. Yield prob. (p) Lead Time 'Original Example' (initial loan deadline for RF, TD = 28, and early payment discounting rate for RF (based on the buyer's credit rating), rRF = 5/365)

Figure 1. Change of optimal production input and profit w.r.t. production yield, loan deadlines, interest rates, and payment terms BL and RF Comparison with Lead Time 'Original Example'

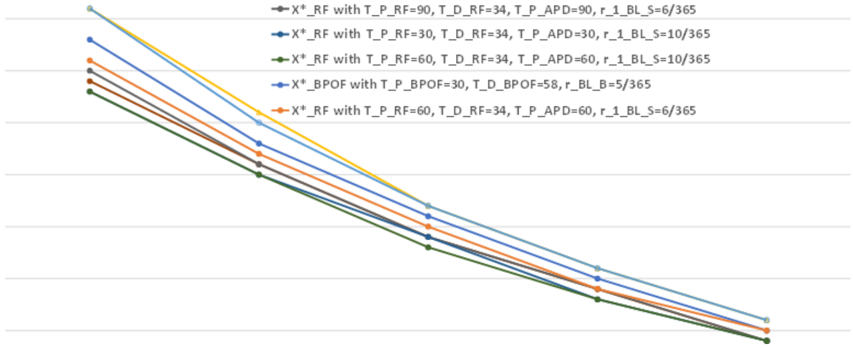


(a) BL and RF Comparison Optimal input (X ∗) w.r.t. Yield prob. (p) Lead Time 'Modified Version' (initial loan deadline for RF, TD = 28, and early payment discounting rate for RF (based on the buyer's credit rating), rRF = 5/365)

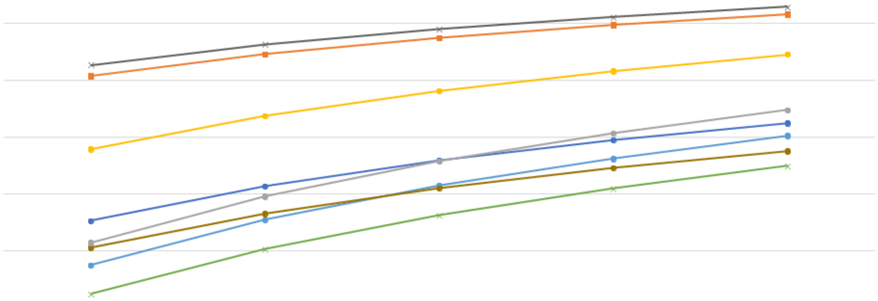


(b) BL and RF Comparison Optimal profit w.r.t. Yield prob. (p) Lead Time 'Modified Version' (initial loan deadline for RF, TD = 28, and early payment discounting rate for RF (based on the buyer's credit rating), rRF = 5/365).

Figure 2. Change of optimal production input and profit w.r.t. production yield, loan deadlines, interest rates, and payment terms BL and RF Comparison with Lead Time 'Modified Version'



(a) RF, APD, and BPOF Comparison Optimal input (X ∗) w.r.t. Yield prob. (p) Lead Time 'Modified Version' (rAPD =rRF = 1/365, rBL(B) = 5/365)



(b) RF, APD, and BPOF Comparison Optimal profit w.r.t. Yield prob. (p) Lead Time 'Modified Version' (rAPD = rRF = 1/365, rBL(B) = 5/365)

Conclusion

In this paper we compared the SCF solutions APD, BPOF, RF applied with initial external financing, and traditional BL for a capital constrained manufacturer subject to uncertain production yield and lead time. We aimed to determine which method works best under which conditions and which parameters dominantly determine the effectiveness of different SCF methods in enhancing the production planning decisions of the manufacturer to both his/her and the buyer's benefit.

We found that for a supplier in need of initial capital for production, extending payment term for RF could be harmful both by causing a severe decrease in production input hence increasing underage possibility, and by causing a severe drop in supplier's profit. Contrary to current practice, a payment term of 90 days or more (Fernandes & Ellram, 2017) is not recommended if the manufacturer is indirect need of initial capital to produce the order. The need to be aware of the manufacturer's capital requirements also points to the importance of information sharing, which is defined as one of the inhibitors for the adoption of SCF (Chakuu, Masi, & God sell:2019). Thus, we recommend prevention of information asymmetry and usage of post shipment financing based on initial working capital of the supplier.

We observe that BPOF helps improve the working capital of both the manufacturer and the buyer since financing is done by an external financial institution based on buyer's credit rating, which provides a more advantageous interest rate to the capital constrained supplier. APD method, on the other hand, provides more flexibility due to not having loan payment deadlines and potential lowering of interest rates, and this method could be particularly helpful to manufacturers with lower production yield rates. For instance, nearshoring approach for critical components may require internal financing to support the supplier with more flexibility.

Benefits from SCF methods increase as production yield probability decreases and lead time fluctuations increase. The random production yield and lead time could decrease the manufacturer's profit substantially while it may not affect the production input as much for higher yield values. For manufacturers with higher possibility of high lead times, the average lead time is considerably higher than the median. In this case the initial loan deadline should be chosen by considering the higher interest rates to be applied if the loan deadline is exceeded, and so that the lower interest rate is more likely to be incurred over the range of all possible lead times.

Payment terms and interest rates are the dominant parameters to determine the benefit and effect of SCF solutions on production planning decisions; and any support from external environment to the supply chains (e. g. any incentives for SCF from the public entities) should aim to improve the payment terms and interest rates especially for critical industries subject to uncertain yield and lead time. For further research, we believe extending the analysis of these SCF methods by involving more supply chain partners and with possible incentives from regulatory bodies would be helpful contributions on this topic. The analysis here could also be extended to different yield and lead time uncertainty models.

While the analysis provides a detailed examination of how different SCF mechanisms interact with production planning under uncertain yield and lead time, the study naturally operates within a set of modeling boundaries. The single-order, single-batch structure and the assumption of fixed technological parameters allow for a clear analytical characterization of the financing schemes, yet more complex production settings—such as multi-order environments, capacity-constrained systems, or dynamic batch sequencing—may reveal additional insights. Similarly, the financing terms are treated as exogenous, whereas in practice interest rates, discount levels, and guarantee structures may evolve endogenously thorough negotiation between buyers, suppliers, and financial institutions. From a managerial perspective, the results underscore the importance of aligning financing choices with the supplier's operational characteristics: yield performance, exposure to lead-time fluctuations, and sensitivity to payment timing jointly determine whether a given SCF method enhances or erodes profitability. In particular, the findings highlight that extended payment terms can render an order unattractive even when production is feasible, and that the relative advantage of APD, RF, or BPOF depends critically on the interplay between yield probability and financing costs. Future research could build on this framework by incorporating heterogeneous suppliers, stochastic demand, adaptive or state-dependent financing contracts, or multi-tier supply chain structures. Exploring these extensions would deepen our understanding of how financial arrangements can be designed to stabilize production decisions and improve the resilience of capital-constrained suppliers operating under uncertainty.

Beyond the general insights discussed above, the analysis yields a set of more detailed managerial implications for firms engaged in supply chain finance arrangements under operational uncertainty. The results indicate that payment timing plays a central role in shaping the economic viability of make-to-order production for capital-constrained suppliers. In particular, extending payment terms may substantially erode expected profitability, and in some cases render an order unattractive, even when production is technologically feasible and demand is secured. This finding suggests that buyers should carefully assess the liquidity position and yield risk profile of their suppliers before imposing long payment delays, especially in environments characterized by uncertain production outcomes or volatile lead times.

The analysis further shows that the relative performance of alternative SCF instruments is highly contingent on operational conditions. Advance payment–based mechanisms and reverse factoring tend to be more effective when yield probabilities are relatively high and financing rates are primarily determined by the buyer's creditworthiness. Under such conditions, early liquidity provision mitigates working capital pressure and allows suppliers to exploit favorable production opportunities. By contrast, when yield uncertainty is pronounced or when interest rate terms are subject to negotiation, BPOF-type arrangements may offer greater flexibility by partially shifting financial risk and smoothing cash-flow exposure over time.

More broadly, the findings underscore that financing choices cannot be treated as exogenous or purely administrative decisions. Yield performance, exposure to lead time variability, and sensitivity to payment timing jointly determine whether a given SCF mechanism enhances or erodes supplier profitability. Effective SCF design therefore requires coordination between operational planning and financial contracting, rather than addressing production and financing decisions in isolation. From this perspective, aligning financing structures with underlying production characteristics can contribute not only to improved firm-level performance, but also to greater stability and resilience of supply chains operating under uncertainty.

Focusing on the decisions that buyers can directly influence, the analysis points to several practical implications. The results suggest that long payment terms should be used with caution when suppliers are capital constrained, as delayed cash inflows may undermine the attractiveness of an order even when production is technically feasible. When yield outcomes are relatively favorable and financing conditions are largely determined by the buyer’s credit standing, advance payment discounts and reverse factoring tend to provide more effective support by easing suppliers’ liquidity pressure at lower cost. In contrast, in environments where yield uncertainty is more pronounced and interest rate terms allow for flexibility, BPOF-type arrangements may offer a more suitable financing alternative. Overall, the findings indicate that payment terms, discount rates, and guarantee policies should be designed in line with suppliers’ operational risk profiles, rather than applied uniformly across transactions.

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