RESEARCH ARTICLE

The mediation effect of blood production on the relationship between master production scheduling and transfusion sustainability in Uganda [version 1; peer review: awaiting peer review]

James Kaconco [ID][1], Betty Nabuuma[1], Jude Thaddeo Mugarura[2]

[1]Mechanical Engineering, Makerere University, Kampala, Uganda
[2]Management Sciences, Makerere University, Kampala, Uganda

Open Peer Review

Approval Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

Abstract

Background: This paper examines the relationship between determinants of blood transfusion sustainability (BTS) that is master production scheduling (MPS) and blood production (BP) of Uganda. The study was founded on four objectives. The study looked at the direct relationship between MPS and the BTS, direct relationship between MPS and BP, direct relationship between BP and BTS. It also assessed how BP mediated the direct relationship between MPS and BTS. The study used a quantitative method.

Methods: A survey questionnaire was administered to collect data from 367 staff of regional blood banks and government university teaching hospital blood banks; and 213 were found to be usable. The main analysis was done using structural equation modeling.

Results: This study found that MPS had a negative and insignificant relationship with the BTS. The study found that relationship between MPS and BP was positive and significant. The study also found that relationship between BP and BTS was positive and significant. The study concluded that the effect of MPS on BTS was fully mediated by BP. It was recommended that blood banks seeking to achieve transfusion sustainability must understand the sector in which they operate. The various stakeholders in the blood supply chain ie blood banks, hospital blood banks, funding agents, ministry of health, must also integrate to enhance the transfusion sustainability. Blood banks performance measures essentially timely delivery was very critical for saving lives of patients in need of blood.

Conclusion: The study has provided a new conceptual framework that investigate the BP mediating effect on the relationship of MPS and BTS, and thus can serve as an incentive for more research to be conducted in this regard of different developing countries. The authors also proposed identifying the effect of other BP factors such

as blood donor management and hospital transfusion practices on
BTS.

Corresponding author: James Kaconco (james.kaconco@mak.ac.ug)

Author roles: Kaconco J: Conceptualization; **Nabuuma B**: Supervision; **Mugarura JT**: Supervision

Competing interests: No competing interests were disclosed.

How to cite this article: Kaconco J, Nabuuma B and Mugarura JT. **The mediation effect of blood production on the relationship
between master production scheduling and transfusion sustainability in Uganda [version 1; peer review: awaiting peer review]**
Emerald Open Research 2022, **4**:40 https://doi.org/10.35241/emeraldopenres.14865.1

First published: 28 Nov 2022, **4**:40 https://doi.org/10.35241/emeraldopenres.14865.1

Introduction
Blood supply and demand is stochastic and prospective donors must meet some requirements to be eligible to donate (Pirabán *et al.*, 2019). Blood supply chain (BSC) stakeholder coordination improves blood transfusion services (Fathian, 2019). Blood transfusion is necessary in addressing any blood shortages, illnesses and disorders in the human body (Lestari *et al.*, 2017; Seed *et al.*, 2018). As such, sustainable blood transfusion remains crucial in extending and improving life for many patients (Kruk *et al.*, 2018; Mulcahy *et al.*, 2017). Developing countries using voluntary non-remunerated donors (VNRDs) are encouraged to pursue strategies that focus on safety, full range, timely delivery and hospital best use of blood products (Jenny *et al.*, 2017; Kajja, 2013; Williamson & Devine, 2013). Safe, adequate and timely blood units are essential for both non-emergent and emergent healthcare for and during transfusion (Checkley *et al.*, 2019; Thomas *et al.*, 2017). However, globally blood supply and quality complaints continue to dominate scholarly works (Al Shaer *et al.*, 2017; Dixon-Woods, 2019; Heffernan *et al.*, 2019; Yates *et al.*, 2017). In Sub-Saharan Africa, lack of safe and adequate blood units lead to about 300,000 pregnant women and 3m children below the age of 5 years dying annually (Checkley *et al.*, 2019). Blood banks have the fundamental responsibility of ensuring transfusion sustainability in a nation while using VNRDs (Achor & Holy, 2016), and the collected blood tested for the transfusion transmission infections (TTIs) (Kyeyune-Byabazaire & Hume, 2019). Pitocco and Sexton (2005) recommended efficient programs such as master production scheduling (MPS), blood production (BP) and blood transfusion sustainability (BTS) would help alleviate the nation's persistent blood safety and adequacy problem. This approach can assist blood banks in enhancing the overall performance, resolving problems and creating new abilities to match blood supply to demand. To ensure that a firm uses the appropriate approaches, it must organize its programs to achieve a sustainable performance. Therefore, blood banks must focus on MPS, BP and BTS programs to accomplish their objectives. Hosseinifard and Abbasi (2018) listed numerous tools and programs which can help blood banks respond to demand changes and save lives of patients. Blood banks need to understand how MPS could affect BTS (Alfonso *et al.*, 2015; Dutta, 2019; Hosseinifard & Abbasi, 2018; Jonsson & Kjellsdotter, 2015; Silva Filho *et al.*, 2013). Blood banks are expected to adapt to the environment and find unique avenues to optimize use of blood products and services (Barro *et al.*, 2018; Bloch *et al.*, 2020; Mulcahy *et al.*, 2017; Sibinga, 2017; WHO, 2011). To improve the results of their businesses, managers have dedicated themselves to identifying program factors that influence performance and how to use them. Thus, this study seeks to discover the connection between MPS and BTS through BP of Uganda. The conceptual framework of the study based on literature review is presented in Figure 1. Review of the literature reveals that no study has investigated more than one variable as predictors of BTS.

Literature review
Master Production Scheduling (MPS)
MPS is an adaptive rolling medium term strategy (3–18 months) used to match supply to demand of specific final items at minimum cost (Jonsson & Kjellsdotter Ivert, 2015; Kohneh *et al.*, 2016). More than a hundred different products can be derived from donated blood (Osorio *et al.*, 2015). Jonsson and Kjellsdotter Ivert (2015) mentioned that partner collaboration supported MPS, and increased organization response to environmental changes. Chaimae and Adil (2020), establish that scheduling and planning of blood collection activities was one of the most important problems at the operational and tactical strategic levels, and has not been widely investigated. Alfonso (2015) found that effective demand and capacity planning increased BTS and BSC system resiliency. Hosseinifard and Abbasi (2018) study in Australia found that centralization of hospitals blood stock, limiting number of hospitals that held blood stock, and aggregating hospitals blood demand increased transfusion sustainability. Literature review indicated that only 32% of BSC published papers considered both supply and demand problems (Pirabán *et al.*, 2019). Furthermore, literature show that MPS and descriptive research are minimally applied in blood transfusion, more so in Africa and Uganda. This study considered MPS blood requirements of supply, demand and perishability for national transfusion services to test the suggested research hypotheses.

Blood Production (BP)
BP referred to as vein to vein starts with the blood donor and ends with the transfused patient (Maeng *et al.*, 2018; Pierskalla, 2006). BP activities also include design of stable production schedules and work distribution to reduce safety and adequacy variability of manufactured blood products (Fathian, 2019). BP can be performed using either centralized or decentralized configurations (Beliën, 2015). The role of BP network is to save human lives in need of transfusion (Maeng *et al.*, 2018). Pitocco and Sexton (2005) informed that operational efficiency for example BP improvements helped resource constrained nations overcome persistent blood shortages. Appropriate BP minimized blood wastage for hospital blood bank in India (Rajvanshi *et al.*, 2019). BP activities enhanced BTS (Jersild & Hafner, 2017). Standard operating procedures (SOPs) should be followed at all BP stages and are essential in promoting sustainability, strengthening safety, enhancing technical capacity and responding to demand changes (Rukundo *et al.*, 2019). Every BP operation solution offered to improve efficiency is not comprehensive and not directly applied as all blood characteristics and factors are not considered (Mansur *et al.*, 2018). Literature review showed that BP publications in blood transfusion services in Africa and Uganda were few and descriptive research is minimally applied. This study operationalized BP as blood collection, blood testing and processing, and blood stock management in order to test the suggested research hypotheses.

Blood collection. Blood collection, from scheduled and walk in donors, purpose is to obtain the quantity of blood units required to meet patient transfusion needs (WHO, 2017). The blood collection using phlebotomy can collect approximately 450 ml. Apheresis donation procedure extract and process the desired blood product in real time and return to donor the remaining fluid (Özener *et al.*, 2019). Blood collection centres were a cause of wastage and the same paper mention that management of loss of blood units from
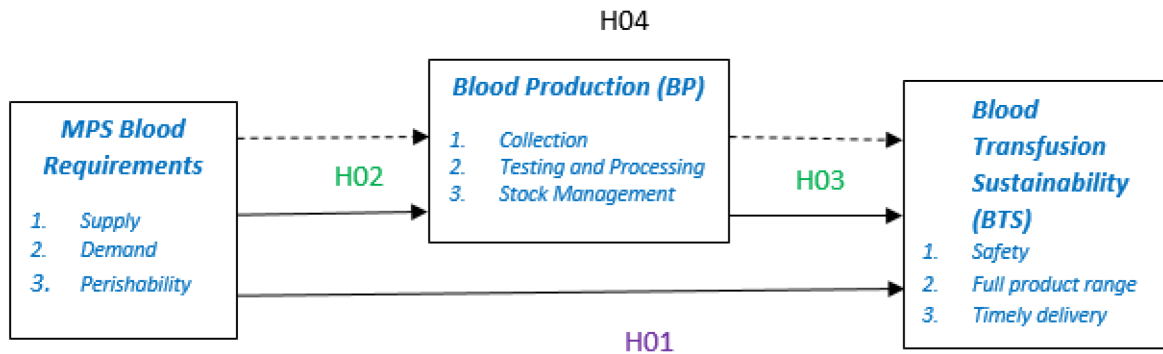
H04

Figure 1. Conceptual Framework.

both first time and repeat donors improved centre performance (Caffrey & Gesinde, 2007). Multi-objective optimization methods and models improve blood collection (Osorio *et al*., 2015).

Blood testing and processing. Blood testing and processing following strict SOPs is concerned with replenishing stocks of safe blood products needed for transfusion (Osorio *et al*., 2015). Kyeyune-Byabazaire and Hume (2019) mentioned that 30% of donated blood in Kampala is used unprocessed. Blood testing ensured TTIs reduction and improved safety in Tanzania (Isangula *et al*., 2016). Kanagasabai *et al.* (2018) mentioned that TTIs percentage prevalence in donated blood in Uganda was on an increase, numbers being 4.3% in 2014, 4.8% in 2015, and 4.4% in 2016. Pathogen reduction enhances transfusion safety, however, achieved with increased BP costs (Ware *et al*., 2018). Leakage and storage during blood testing and processing were the major causes of blood discard, and staff training is the recommended appropriate intervention (Rajvanshi *et al.*, 2019). Blood testing then processing have the least number of referenced papers (Osorio *et al*., 2015; Pirabán *et al.*, 2019).

Blood stock management. Blood stock management using either periodic or continuous review must guarantee safety and adequacy of blood products (Pirabán *et al.*, 2019). Furthermore, assigned stock and perishability property increased the complexity of blood stock management (Pirabán *et al.*, 2019). Limited shelf life greatly affected the quality of active factors in the respective blood product for transfusion or fractionation and blood availability (Dobbin & Cotton, 2009; Jersild & Hafner, 2017). Radio frequency identification (RFID) in blood stock management ensured safe and efficient operations, positive patient outcomes, supported smart data entry and blood traceability (Arora & Gigras, 2018; Coustasse *et al.*, 2015). A reliable blood stock management system is recommended to a changing environment (Mansur *et al*., 2018).

Blood Transfusion Sustainability (BTS)
A robust sustainable blood transfusion system is one that performed well on the following three criteria: blood products safety levels, provided blood products for the full range of clinical and transfusion applications, and delivered

blood in a timely fashion such that patient health and transfusion preparedness are not unduly compromised (Mulcahy *et al.*, 2017). For example (Barro *et al.*, 2018; Sibinga, 2017; WHO, 2011) recommend that all national BSC critical activities should be coordinated in order to achieve transfusion sustainability. Premised on the findings and results of earlier studies and suggested criteria, the present study uses three indicators, safety level, full range and timely delivery, to measure the BTS of Uganda.

Developing hypotheses and conceptual framework
Master production scheduling and blood transfusion sustainability
Effective MPS requirements (demand and supply) were established to increase BTS (Alfonso *et al.*, 2015). MPS influenced successful organization outcomes (Jonsson & Kjellsdotter Ivert, 2015; Osorio *et al.*, 2015). MPS was used to map problems and improvement opportunities for Indonesia blood bank (Mansur *et al.*, 2019). The researchers found that there is a positive link between MPS and BTS. Partner collaboration supported MPS, and increased organization response to environmental changes (Jonsson & Kjellsdotter Ivert, 2015). Aggregating blood demand forecast increased sustainability and resilient of transfusion service (Silva Filho *et al.*, 2013). The above discussion clearly shows that there is a relationship between MPS and BTS. Therefore, the following hypothesis is proposed.

H01: Master production scheduling has a positive effect on blood transfusion sustainability.

Master production scheduling and blood production
While blood is essential in the healthcare management, (Mansur *et al.*, 2018) assert that donor blood supply is irregular and blood demand oscillates overtime. That is to say blood production is stochastic. Perishability and limited shelf life add complexity and cost to blood stock management (Pirabán *et al.*, 2019); the same study informed that replenishment stock levels, assigned inventory and simple perishable inventory management practices improved timely delivery of blood products. Although some of the previous studies focused on BP operations (Beliën, 2015; Fathian, 2019; Pirabán *et al.*, 2019; Zahraee *et al.*, 2015), these studies

were not able to give a comprehensive answer to the question of how MPS impact BP. Thus, this study will attempt to bridge this gap by linking MPS with BP. The present study hopes to make a vital contribution to the MPS literature by scrutinizing the relationship between MPS and BP, and providing a deeper understanding of how MPS is able to impact BP. Therefore, the author proposed the following hypothesis:

H02: Master production scheduling has a positive effect on blood production.

Blood production and blood transfusion sustainability

BP literature most often pointed out that BP is positively associated with transfusion sustainability. Several empirical studies have been carried out in an attempt to understand how BP operations are associated with transfusion sustainability. BP solution methods and models improved blood transfusion services (Beliën, 2015; Fathian, 2019; Pirabán *et al.*, 2019; Zahraee *et al.*, 2015). Every BP operation solution offered to improve efficiency is not comprehensive and not directly applied as all blood characteristics and factors are not considered (Mansur *et al.*, 2018). Continued optimal function of a blood bank improved transfusion sustainability (Jovanovi, 2013). Quality of BP planning process affected efficiency of blood bank performance (Silva Filho *et al.*, 2013). The preceding discussion has shown that previous studies support the relationship between BP and BTS. However, very little empirical studies on blood banks have been carried out in Africa and Uganda. Hence, there is an urgent need to examine BP in this context. Therefore, the author put forward the following hypothesis.

H03: Blood production have positive effect on blood transfusion sustainability.

Master production scheduling, blood production and blood transfusion sustainability

MPS research in the recent past were not able to provide insights on how it can influence BTS through BP. MPS has a substantial and beneficial effect on BTS (Osorio *et al.*, 2015). A Literature review confirm the beneficial effect of BP (Maeng *et al.*, 2018; Rajvanshi *et al.*, 2019), and MPS (Jonsson & Kjellsdotter Ivert, 2015; Kohneh *et al.,* 2016; Mansur *et al.,* 2019) on BTS. Thus, BP program may also play an indirect significant role in enhancing BTS. In this context, MPS and BP are complementary programs (Laaksonen & Peltoniemi, 2018). Surprisingly, very few studies have examined the combined impact of MPS and BP on the BTS. Quality, value co-creation and sustainability should be achieved together (Aquilani *et al.*, 2016). Hence, successful implementation of BP is very dependent on MPS. Therefore, the effects of MPS on BP could result in better BTS. In the light of the disparity in current knowledge, this research seeks to fill the gap by studying MPS and BTS in the hope of mediating them with BP, thereby obtaining a better comprehension of the relationship between MPS and BTS. This has led to the following hypothesis.

H04: Blood production mediate the relationship between master production scheduling and transfusion sustainability.

The findings of related previous literature are used to develop a conceptual framework that is underpinned by the dynamic capability theory. Hence, the proposed model shows the relationship between the three variables and their impact on blood banks in Uganda. These variables are categorized as: (1) independent variable: master production scheduling; (2) dependent variable: blood transfusion sustainability; (3) mediation variable: BP (Figure 1). The present study is the one of the few studies investigating the BP as a mediation variable on the relationship of MPS with BTS in order to gain a deeper understanding insight of this relationship.

Methods
Data collection and sampling design
The current study adopted a descriptive cross sectional survey research design. Cold chain staff and transfusing staff were selected to fill a self-administered questionaire as a data collection tool intended to examine the opinion of respondents on the relation between MPS and BTS through BP. In addition, this research design permits the collection and analysis of quantitative data using descriptive and inferential statistics. Simple random sampling method was used to select the cold chain respondents from the seven regional blood banks ((Nakasero, Arua, Fort-Portal, Gulu, Mbale, Kitovu, Mbarara) and transfusing staff from eight government teaching hospital blood banks ((Makerere, Mbarara, Gulu, Busitema, Soroti, Kabale, Lira, Mbale). The sampling was aided by the data obtained from Uganda Blood Transfision Services (UBTS) and Ministry of Health (Ministry Of Health, 2020; UBTS, 2018). The aim purpose of random selection of blood banks was to obtain national coverage of respondents that were experienced and knowledgeable in blood operations. A selection of 367 respondents was considered adequate for analysis. Data were collected through a pre-tested questionnaire. All questionnaire items for the study variables were measured using a Five-Point Likert Scale which ranged from strongly disagree (1) to strongly agree (5). BP was measured using questionnaire item inputs from (Beliën, 2015; Jovanovi, 2013; Kralievits *et al.*, 2015). Items used to measure MPS were adapted from the questions designed by (Hosseinifard & Abbasi, 2018; Mansur *et al.*, 2019). Suggested criteria by (Mulcahy *et al.*, 2017) was used to develop questionnaire items to evaluate BTS.

Data analysis
Preliminary data, analysis from 213 usable filled questionnires, was done using SPSS in order to address the problems of missing values, outliers and non-normality. The main analysis was done using SPSS AMOS23. Assessment of the measurement model was made by considering reliability and validity values while the hypotheses were tested using bootstrapping method to assess the significance of the claimed relationships. MPS and BP were each analysed using a two-item scale. Finally, a three-item scale was used to analyse BTS.

Ethics and consent

This study obtained ethical approval from Mulago Hospital Research Ethics Committee (MHREC REC) under the protocol number MHREC-2022-081 and Uganda Council for Science and Technology (UNCST). Information regarding the role of each participant was explained and respondents signed consent forms.

Results and findings

The study used SPSS AMOS23 to test the results of the hypotheses. The first step in structural equation modeling is to evaluate the measurement model. Figure 2 presents the measurement model along with the item loadings.

Measurement model assessment

SEM was implemented to examine the validity of the constructs. Results show two types of validity; convergent and discriminant validity. Both validity analyses are discussed below.

Confirmatory factor analysis

The factor loadings were verified using Cronbach's Alpha, Composite reliability and Average Variance Extracted. According to (Hair *et al.*, 2014) the threshold for convergent validity measure is a standardized factor loading greater than 0.5 for each item indicating the measurement items significantly defined the proposed latent variables; the values for composite reliability should be greater than 0.7 for all the items at a 5% level of significance and the value for alpha should be greater than 0.7 indicating high internal consistency among the measurement variables. All the values met the initial criteria and thus convergent validity was ensured; Table 1.

As per model fit indices, CMIN/DF was 0.970, GFI was 0.991, CFI was 1.000, TLI was 1.017, RMSEA was 0.000, and SRMR was 0.024. The model fit verification was excellent on at least three measures which is a reasonable effect for analysis (Hair *et al.*, 2010). Figure 2, presents the diagrammatic presentation of the CFA output.

Discriminant validity

The study assessed discriminant validity by measuring the hetrotrait – monotrait (HTMT ratio) to the respective correlation coefficients. To achieve discriminant validity, the ratios should be less than 0.85 (Henseler *et al.*, 2015), as was the case in Table 2. Hence, the discriminant validity of the construct is assured.

Another concern in model estimation is multicollinearity, that is, high correlation among two predicting variables. Coefficients of 0.8 are usually considered as high, which may cause a confounding effect in the model estimation. The highest coefficient score of 0.56, however, indicates multicollinearity was not a challenge to the reliability of the model estimated. Therefore, the data was valid for model estimation.
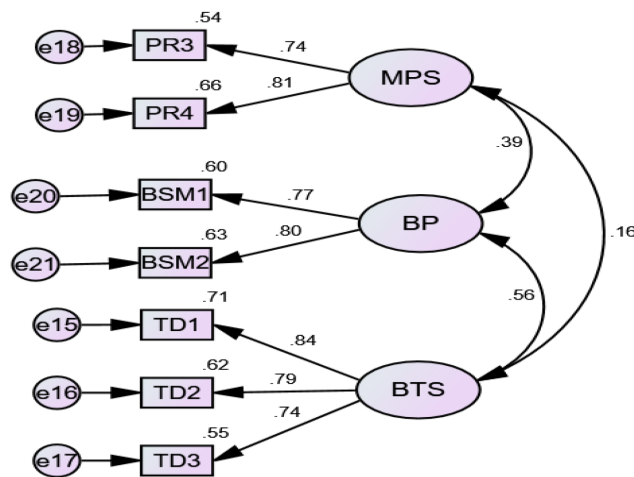
CFA - BP Mediation Measurement Model Analysis

Chi-square = 6.689 (11 DF)
p = .824
CFI = 1.000
TLI = 1.017
GFI = .991
RMSEA = .000
RMR = .016

Figure 2. CFA – BP Measurement Model Analysis (Factor Loadings).

Table 1. Loadings, Cronbach Alpha, Reliability, and Convergent Validity – BP mediation Measurement Model.

Items	Loadings	Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Master Production Scheduling (MPS)		0.747	0.750	0.600
PR3	0.735			
PR4	0.812			
Blood Transfusion Sustainability (BTS)		0.894	0.836	0.630
TD1	0.845			
TD2	0.790			
TD3	0.743			
Blood Production (BP)		0.751	0.764	0.618
BSM1	0.775			
BSM2	0.797			

Table 2. Heterotrait – Monotrait Ratio.

	BP	MPS	BTS
BP			
MPS	0.391		
BTS	0.558	0.162	

Structure equation modelling

After the reliability and validity checks, the main model was estimated using the SEM approach in Amos. Table 3 and Table 4, Figure 3 presents the results of the model estimation. The estimation was based on Bootstrap Bias-Corrected confidence interval at 95%, with 5000 bootstrap samples. Results show the direct effects (Table 3) and indirect effects (Table 4). The direct effects are used to test the direct hypotheses while the indirect effect was used to test the mediation hypothesis (Hair et al., 2010).

Path Model (Bootstrapping Results)

The results of Table 3, show a positive and significant relationship between MPS and BP ($\beta = 0.390$; $p < 0.001$). Relationship between MPS and BTS is negative and insignificantly ($\beta = -0.066$, $p = 0.485$), while BP has a positive and strong relationship ($\beta = 0.583$; $p < 0.001$) with BTS that is significant. Hence, hypothesis H02 and H03 are supported while H01 is not supported. Figure 3 shows the path coefficients.

The result for mediation shows that MPS has a significant indirect effect on BTS through the mediation of BP ($\beta = 0.228$, $p < 0.001$). Thus BP mediates the relationship between MPS and BTS. Hence, H04 is supported. However, the direct effect of MPS to BTS is negative and insignificant ($\beta = -0.066$, $p = 0.485$); an indication of full mediation. Therefore, BP fully mediates the relationship between MPS and BTS.

Discussion

The first hypothesis (H01) suggested the positive impact of MPS and BTS, and the results did not support the hypothesis. The results of the study are similar to previous one (Pirabán et al., 2019), that perishability and limited shelf life add complexity and cost to blood stock management and affected transfusion sustainability. Hence, the first hypothesis (H01) of this study is well-substantiated by previous works. The positive relationship was based on none related studies that MPS positively affected organization performance. A potential reason behind this lack of relationship could be limited resources (Dutta, 2019), poor blood bank and hospital collaboration and coordination (Jonsson & Kjellsdotter Ivert, 2015; Kyeyune-Byabazaire & Hume, 2019) and perishability dimension items after CFA remaining key indicators of MPS. The second hypothesis (H02) suggested the positive effect of MPS on BP. Results of the data analysis reveal that MPS had a beneficial and strong influence on BP and significant. The outcomes of this study are congruous with those obtained by (Silva Filho et al., 2013), that quality of planning process affected efficiency of blood bank. Hence, the second hypothesis (H02) of this study is well-substantiated by previous works. The third hypothesis (H03) proposed the

Table 3. Direct Effects (Hypotheses 1 to 3).

Hypothesis	Relationship	Std β	S.E	CR	P value	Remark
H01	MPS ---> BTS	-0.066	0.138	-0.739	0.485	Not Supported
H02	MPS ---> BP	0.390	0.118	3.913	0.000	Supported
H03	BP ---> BTS	0.583	0.132	5.734	0.000	Supported

Table 4. Indirect Effects / Mediation (Hypothesis H04).

Hypothesis	Relationship	Std β	SE	CR	Confidence Interval		P Value	Conclusion
					Lower Bound	Upper Bound		
H04	MPS --> BP-- > BTS	0.228	0.138	2.192	0.129	0.368	0.000	H04, supported; Full Mediation
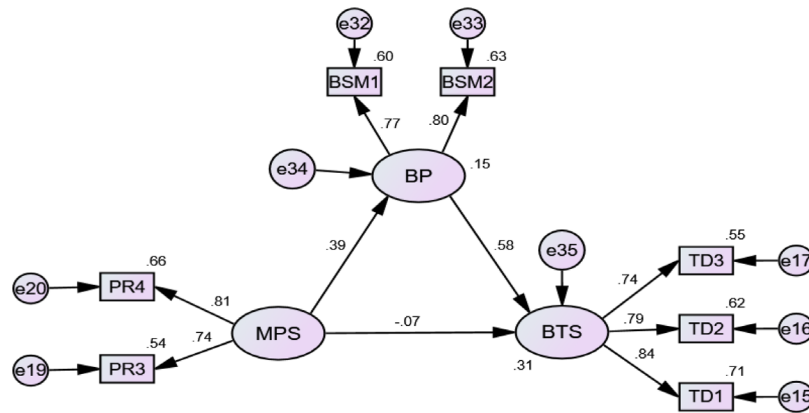
CFA - BP Mediation Measurement Model Analysis

Figure 3. Path Model (Coefficient and Model Fit values).

relationship between BP and BTS, and the study has demonstrated a postive and significant relationship between the two variables like in previous studies (Beliën, 2015; Fathian, 2019; Pirabán *et al.*, 2019; Zahraee *et al.*, 2015). Hence, H03 is in agreement with the existing literature. The fourth hypothesis (H04) suggested the mediating role of BP and results indicate full mediating role of BP between MPS and BTS at 95% confidence interval. The current study has empricially demonstrated the full mediating role of BP in the MPS relationship with BTS.

Conclusion

The study was founded on four main objectives. Firstly, the study looked at the direct relationship between MPS and BTS. Secondaly, the study asssed the relationship between MPS and BP. Thirdly, it assessed the relationship between BP and BTS. Lastly, the study assessed the mediating effect of BP on the relationship between MPS and BTS. The study concluded that MPS had a negative and insignificant effect on BTS, such that high levels of MPS blood perishability requirement lead to lower BTS. Further, it was concluded that the effect of MPS on to BTS was fully mediated by BP. Finally, the study concluded that the effect of MPS on BP and effect of BP on to BTS were positive and significant.

As with other studies, the present study has made theoretical and empirical contributions to the existing body of knowledge. The study has provided a new conceptual framework

that investigate the BP mediating effect on the relationship of MPS and BTS. This effect has been demonstrated by the present study, and thus can serve as an incentive for more research to be conducted in this regard in blood banks of different developing countries. It was recommended that blood banks seeking to achieve BTS must invest in the MPS and BP programs. This includes MPS blood perishability requirement and BP stock management. Furthermore, the findings of this study may be useful in helping blood banks, business owners, practitioners, and decision makers ensure a good organizational performance. Put simply, MPS and BP can help blood banks in attaining BTS. Finally, the various national units of the blood supply chain must coordinate and collaborate to enhance smooth blood transfusion services.

Blood banks performance measure such as timely delivery is very critical for saving lives of patients in need of blood. Blood banks must also invest in blood collection, testing and processing to help them achieve the safety levels and full range of blood products needed for transfusion.

Limitation of the study and future research
This study has developed a model which focused on the blood banks in Uganda, and therefore there is a need for future studies to examine the framework of this study in the context of other countries and in different industries, in order to be able to generalize the results. The authors also proposed identifying the effect of other BP factors such as blood donor management and hospital transfusion practices on BTS.

Data availability
The data that support the findings of this study are not publicly available due to confidentiality clauses and are available from the corresponding author upon reasonable request (james.kaconco@mak.ac.ug).

References

Achor OU, Holy B: **Comparative Study on Some Biochemical Parameters in Stored Whole Blood in Standard Blood Bank and Traditional Refrigerator.** *JMSCR.* 2016; **04**(03): 9824–9832.
Publisher Full Text

Alfonso E, Xie X, Augusto V: **A simulation-optimization approach for capacity planning and appointment scheduling of blood donors based on mathematical programming representation of event dynamics.** *IEEE Int Conf Automation Sci Eng.* 2015; **71131005**: 0–5.
Publisher Full Text

Al Shaer L, Sharma R, Abdulrahman M: **Analysis of blood donor pre-donation deferral in Dubai: Characteristics and reasons.** *J Blood Med.* 2017; **8**: 55–60.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Aquilani B, Silvestri C, Ruggieri A: **Sustainability, TQM and value co-creation processes: The role of critical success factors.** *Sustainability.* 2016; **8**(10): 995.
Publisher Full Text

Arora M, Gigras Y: **Importance of supply chain management in healthcare of third world countries.** *International Journal of Supply and Operations Management.* 2018; **5**(1): 101–106.
Publisher Full Text

Barro L, Drew VJ, Poda GG, *et al.*: **Blood transfusion in sub-Saharan Africa: understanding the missing gap and responding to present and future challenges.** *Vox Sang.* 2018; **113**(8): 726–736.
PubMed Abstract | **Publisher Full Text**

Beliën J: **Supply Chain Management of Blood Products A Literature Review.** In: *KBI.* 2015.

Bloch EM, Gehrie EA, Ness PM, *et al.*: **Blood Transfusion Safety in Low-Resourced Countries: Aspiring to a Higher Standard.** *Ann Intern Med.* 2020; **173**(6): 482–483.
PubMed Abstract | **Publisher Full Text**

Caffrey L, Gesinde M: **Donors and Blood Collection.** *Practical Transfusion Medicine.* 2007; **44**: 239–249.
Publisher Full Text

Chaimae M, Adil B: **Blood collection supply chain management: A critical review and future perspective.** *IEEE 6th International Conference on Optimization and Applications (ICOA).* IEEE, 2020.
Publisher Full Text

Checkley L, Motwani G, Wange IC, *et al.*: **Assessment of blood donation and transfusion in Eastern Uganda: A mixed-methods study.** *Ann Glob Health.* 2019; **85**(1): 59.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Coustasse A, Meadows P, Hall RS 3rd, *et al.*: **Utilizing Radiofrequency Identification Technology to Improve Safety and Management of Blood Bank Supply Chains.** *Telemed J E Health.* 2015; **21**(11): 938–945.
PubMed Abstract | **Publisher Full Text**

Dixon-Woods M: **Harveian Oration 2018: Improving quality and safety in healthcare.** *Clin Med (Lond).* 2019; **19**(1): 47–56.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Dobbin J, Cotton S: **True Blood : challenges of the blood supply chain in England.** *CILT SUPPLY CHAIN.* 2009; **11**.

Dutta P: **Blood Supply Chain Networks in Healthcare: Game Theory Models and Numerical Case Studies.** 2019.
Publisher Full Text

Fathian HH: **Management of Blood in the Context of Supply Chain Network.** *Archives of Blood Transfusion & Disorders.* 2019; **1**(5): 3–5.
Reference Source

Hair JF, Black WC, Babin BJ: **Multivariate Data Analysis.** Pearson, 2010.
Reference Source

Hair JF, Sarstedt M, Hopkins L, *et al.*: **Partial least squares structural equation modeling (PLS-SEM): An emerging tool in business research.** *European Business Review.* 2014; **26**(2): 106–121.
Publisher Full Text

Heffernan A, Cooke GS, Nayagam S, *et al.*: **Scaling up prevention and treatment towards the elimination of hepatitis C: a global mathematical model.** *Lancet.* 2019; **393**(10178): 1319–1329.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Henseler J, Ringle CM, Sarstedt M: **A new criterion for assessing discriminant validity in variance-based structural equation modeling.** *J of the Acad Mark Sci.* 2015; **43**(1): 115–135.
Publisher Full Text

Hosseinifard Z, Abbasi B: **The inventory centralization impacts on sustainability of the blood supply chain.** *Comput Oper Res.* 2018; **89**: 206–212.
Publisher Full Text

Isangula KG, Brownie S, Mahimbo A, *et al.*: **Blood, donors and dollars: Rethinking financial sustainability of safe blood services in Tanzania.** *Global Journal of Medicine and Public Health.* 2016; **5**(4): 1–7.
Reference Source

Jenny HE, Saluja S, Sood R, *et al.*: **Access to safe blood in low-income and middle-income countries: Lessons from India.** *BMJ Glob Health.* 2017; **2**(2): e000167.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Jersild C, Hafner V: **Blood Transfusion Services.** *International Encyclopedia of Public Health, 2nd Edition.* 2017; **1**: 247–253.
Publisher Full Text

Jonsson P, Kjellsdotter Ivert L: **Improving performance with sophisticated master production scheduling.** *Int J Prod Econ.* 2015; **168**: 118–130.
Publisher Full Text

Jovanovi R: **Planning the use of Lean Six Sigma as a framework for blood**

bank management improvements. *International Journal of Industrial Engineering and Management (IJIEM).* 2013; **4**(4): 237–244.
Reference Source

Kajja I: **Appropriate clinical use of blood in Uganda.** *International Society of Blood Transfusion.* 2013; **8**(1): 214–216.
Publisher Full Text

Kanagasabai U, Chevalier MS, Drammeh B, *et al.*: **Trends and gaps in national blood transfusion services — 14 Sub-Saharan African Countries, 2014–2016.** In: *MMWR Morb Mortal Wkly Rep.* 2018; **67**(50): 1392–1396.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Kohneh JN, Teymoury E, Pishvaee MS: **Blood products supply chain design considering disaster circumstances (Case study: earthquake disaster in Tehran).** *Journal of Industrial and Systems Engineering.* 2016; **9**: 51–72.
Reference Source

Kralievits KE, Raykar NP, Greenberg SLM, *et al.*: **The global blood supply: a literature review.** *Lancet.* 2015; **385 Suppl 2**: S28.
PubMed Abstract | **Publisher Full Text**

Kruk ME, Gage AD, Arsenault C, *et al.*: **High-quality health systems in the Sustainable Development Goals era: time for a revolution.** In: *Lancet Glob Health.* 2018; **6**(11): e1196–e1252.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Kyeyune-Byabazaire D, Hume HA: **Towards a safe and sufficient blood supply in Sub-Saharan Africa.** *ISBT Science Series.* 2019; **14**(1): 104–113.
Publisher Full Text

Laaksonen O, Peltoniemi M: **The Essence of Dynamic Capabilities and their Measurement.** *International Journal of Management Reviews.* 2018; **20**(2): 184–205.
Publisher Full Text

Lestari F, Anwar U, Nugraha N, *et al.*: **Forecasting demand in blood supply chain (case study on blood transfusion unit).** *Proceedings of the World Congress on Engineering.* 2017; **II**: 5–8.
Reference Source

Maeng JJ, Sabharwal K, Ülkü MA: **Vein To vein: Exploring blood supply chains in Canada.** *Journal of Operations and Supply Chain Management.* 2018; **11**(1): 1–13.
Publisher Full Text

Mansur A, Vanany I, Arvitrida NI: **Blood supply chain challenges: Evidence from Indonesia.** *Proc Int Conf Ind Eng Oper Manag.* 2019; **2019**: 1667–1674.
Reference Source

Mansur A, Vanany I, Indah Arvitrida N: **Challenge and opportunity research in blood supply chain management: a literature review.** *MATEC Web of Conferences.* 2018; **154**: 01092.
Publisher Full Text

Ministry of Health: **Annual Health Sector Performance Report, Financial Year 2019/20.** Ministry of Health, Uganda. 2020.
Reference Source

Mulcahy A, Kapinos K, Briscombe B, *et al.*: **Toward a Sustainable Blood Supply in the United States: An Analysis of the Current System and Alternatives for the Future.** In: *RAND Corporation.* 2017.
Publisher Full Text

Osorio AF, Brailsford SC, Smith HK: **A structured review of quantitative models in the blood supply chain: A taxonomic framework for decision-making.** *Int J Prod Res.* 2015; **53**(24): 7191–7212.
Publisher Full Text

Özener OÖ, Ekici A, Çoban E: **Improving blood products supply through donation tailoring.** *Comput Oper Res.* 2019; **102**: 10–21.
Publisher Full Text

Pierskalla WP: **Supply Chain Management of Blood Banks.** In: *Oper Res Health Care.* 2006; 103–145.
Publisher Full Text

Pirabán A, Guerrero WJ, Labadie N: **Survey on blood supply chain management: Models and methods.** *Comput Oper Res.* 2019; **112**: 104756.
Publisher Full Text

Pitocco C, Sexton TR: **Alleviating blood shortages in a resource-constrained environment.** *Transfusion.* 2005; **45**(7): 1118–1126.
PubMed Abstract | **Publisher Full Text**

Rajvanshi R, Kothari F, Dighe M, *et al.*: **ANALYSIS OF REASONS FOR DISCARDING BLOOD AND BLOOD COMPONENTS IN A BLOOD BANK OF TERTIARY CARE HOSPITAL IN VADODARA.** *Int J Sci Res.* 2019; **8**(6): 8–10.
Reference Source

Rukundo HAM, Taremwa IM, Muwanguzi E, *et al.*: **Assessment of the quality of stored blood for transfusion at mbarara regional referral hospital, Southwestern Uganda.** *J Blood Med.* 2019; **10**: 161–169.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Seed CR, Hewitt PE, Dodd RY, *et al.*: **Creutzfeldt-Jakob disease and blood transfusion safety.** *Vox Sang.* 2018; **113**(3): 220–231.
PubMed Abstract | **Publisher Full Text**

Sibinga CTS: **Existing and Recommended Legislative Framework for a National Blood Transfusion Policy.** *Global Journal of Transfusion Medicine.* 2017; **2**(2): 79–83.
Publisher Full Text

Silva Filho OS, Carvalho MA, Cezarino W, *et al.*: **Demand forecasting for blood components distribution of a blood supply chain.** *IFAC Proceedings Volumes.* 2013; **46**(24): 565–571.
Publisher Full Text

Thomas J, Ayieko P, Ogero M, *et al.*: **Blood Transfusion Delay and Outcome in County Hospitals in Kenya.** *Am J Trop Med Hyg.* 2017; **96**(2): 511–517.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

UBTS: **UBTS 2018 Staff Positions.** 2018.

Ware AD, Jacquot C, Tobian AAR, *et al.*: **Pathogen reduction and blood transfusion safety in Africa: strengths, limitations and challenges of implementation in low-resource settings.** *Vox Sang.* 2018; **113**(1): 3–12.
PubMed Abstract | **Publisher Full Text**

WHO: **Blood System Aide-Mémoire Key elements**. 2011; **11**(01).

WHO: **Regional Status Report on Blood Safety and Availability 2016.** In: *WHO Library Cataloguing.* 2017.
Reference Source

Williamson LM, Devine DV: **Challenges in the management of the blood supply.** *Lancet.* 2013; **381**(9880): 1866–1875.
PubMed Abstract | **Publisher Full Text**

Yates N, Stanger S, Wilding R, *et al.*: **Approaches to assessing and minimizing blood wastage in the hospital and blood supply chain.** *ISBT Science Series.* 2017; **12**(1): 91–98.
Publisher Full Text

Zahraee SM, Rohani JM, Firouzi A, *et al.*: **Efficiency Improvement of Blood Supply Chain System Using Taguchi Method and Dynamic Simulation.** *Procedia Manuf.* 2015; **2**: 1–5.
Publisher Full Text