Additive Manufacturing/3D in the Optimization of Nigeria Vaccine Supply Chain

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***Abstract*- Introduction**: This study captures the perspectives of stakeholders on optimization of Nigeria vaccine supply chain with 3D printing technology. Temperature excursion, cold chain maintenance and the attendant issues of maintaining vaccine integrity across the supply chain network till the last mile remain a critical bottleneck to immunization and vaccine coverage. This study aimed at taking a pragmatic approach to assessing the awareness, acceptability, feasibility, and preparedness of the Nigerian supply chain professionals to take up the innovation of 3D technology to optimize the vaccine supply chain and immunization coverage in the Nigeria context. Internet-based questionnaire (Google Form) was used to reach different public health supply chain professionals in Nigeria. A community of professionals whose works relates to the supply chain of public health commodity was selected as the sampling frame. This community includes some supply chain professionals in Nigeria who have identified as part of the International Association of Public Health Logisticians, IAPHL. There are 200 valid responses, of which 70.5% were males, and 29.5% were females. The most frequent age group was 31 – 40 (56.5%). 3D printing recorded very high acceptability and feasibility with a minimum of 80.8% and a maximum of 100% among respondents. Similarly, the feasibility of 3D printing in Nigeria vaccine supply chain recorded high ratings ranging from 75.0 % to 100.0% among professionals of various specializations. International political will was rated with the highest (96.0%) preparedness to take up new technologies/innovations in Nigeria vaccine supply chain while the national political will was rated 54.0%. This study found that the majority of participants knew the vaccine supply chain and had relatively adequate knowledge/awareness of 3D printing. The overall acceptability and feasibility of 3D printing were generally high. Preparedness of Nigeria vaccine supply chain to take up 3D printing was rated high for international political will, private sector involvement and collaboration, readiness in regulatory and policy, workforce know-how and national political will. It is therefore concluded that 3D printing can be used to optimizing Nigeria vaccine supply chain due to high acceptability, feasibility, market value, and its economic impact.

Keywords: 3D printing, vaccine, supply chain, acceptability, feasibility, preparedness.

I. Introduction

Exposure to vaccine-preventable diseases, poor sanitation, and inaccessibility to quality health care and clean water all contribute to the high death rate of children worldwide. Vaccines are critical to public health strategy to reduce child morbidity and mortality associated with vaccine-preventable disease such as polio [1]. Vaccines prevent over two million child deaths worldwide annually [2]. Despite the successes achieved with routine immunization (RI) coverage, vaccine-preventable diseases remain the most common cause of childhood mortality, with an estimated 19.4 million infants worldwide not reached with routine immunization services [3].

3D printing also called additive manufacturing (AM), turns digital 3D models into objects by building them up in layers. This technology enables small quantities of customized goods to be produced at relatively low costs [4]. Many sectors such as automotive replacement parts, dental crowns, artificial limbs, aviation industry, clothing and even in foodstuff use 3D printers [5]. Due to its characteristics, the method is seen as a disruptive technology for supply chain management.

II. POTENTIAL OF 3D PRINTING

Cardinal to 3D printing and potential benefits is simplicity [6]. This simplicity involves producing products on-demand and locally and as such, making supply chains to become shorter, leaner, and less complicated [6], [7]. Another key benefit in this era of global warming and advocacy to go green is that 3D printing would win some sustainability marks for any company/society adopting it [8]. The benefits of 3D printing methods over the conventional manufacturing methods as summarized by Özceylan *et al.* [4] include; no need for tooling,

feasibility of producing small production batches economically, possibility for quickly change design, product optimization for function, more economical custom product manufacturing plus the ability to produce complex geometries, potential for more accessible supply chains with shorter lead times and lower inventories.

Generally, a Mckinsey report suggests that 3D printing market would be worth between $180 billion and $490 billion by 2025 [8]. Experts and big industry players in vaccine production and research have shown some interest in 3D printing [8]. A synthetic biological giant, Craig venter had predicted that 3D vaccine printing would be a big thing in the future of public health to fight epidemics [9]. The combination of multiple doses and types of vaccines using 3D printing is also another potential use of disruptive technology. This approach can be beneficial in reducing the strain of intruding new vaccines in the already strained vaccine supply chain.

III. CHALLENGES OF 3-D PRINTING

One of the challenges of 3D printing is how to make a business case that presents it to decision-makers as no threat to the existing infrastructure and process of manufacturing [10]. Another key drawback is the issue around intellectual property rights. That is how digital products would be protected from pirates and counterfeiters [8].

IV. GOING FORWARD

Vaccines must reach the population that needs them for any immunization program to be a success [11]. 3D printing is still novel and growing at a rate that could be disruptive to the supply chain of any industry [12]. It has already gained relevance in healthcare to about 7-9% (Goel & Goel 2015). With the price of personal 3D printer coming down to about $1,000, there seems to be a higher potential for adoption based on cost.

3D printing clearly shows some potential, including making products, in this case, vaccines, just-in-time/on-demand, make the supply chain more agile and leaner and improve quality while reducing the cost of logistics. It is therefore imperative to consider how the developing countries can begin to set the stage for its adoption to effect more extensive vaccine and immunization coverage. It is this agenda that we intend to set in this work.

V. SUPPLY CHAIN AND 3-D PRINTING

In today's competitive market, satisfying the dynamic demands of customers on time has vital importance without budging form quality and profitability. Today, 3D printing has the potential to become the basis for new solutions in supply chain management [14]. 3D printing can take several opportunities instead of conventional manufacturing such as a reduction in lead times, inventories, set up times, safety stocks, some assemblies, wastes; increment in product qualities and ability to produce complex-shaped products. 3D printing can decrease the number of stages in the traditional supply chain because of needing fewer components, and it can manufacture products near the customers [15]. Niaki & Nonino [16] reviewed the literature about 3D printing in eight different categories: technology selection, supply chain, product design and production cost models, environmental aspects, strategic challenges, manufacturing systems, open-source innovation and business models and economics and researched the effectiveness of 3D printing in different environments and industries, business strategies, business models and processes. Besides the above studies considering 3D printing, some studies are investigating the effect of 3D technology on supply chain management. Walter *et al.* [14] presented supply chain solutions made possible by both the centralized and decentralized applications of 3D printing. This study explores the knowledge of 3D printing among supply chain professionals and also determines its acceptability, feasibility as well as preparedness of Nigeria vaccine supply chain to take up this emerging technology.

VI. METHODS

We conducted an electronic survey using an internet-based questionnaire to reach different professionals with experience of Nigeria supply chain of vaccines. The samples cut across different levels of operation, geography, and areas of practice. The population size of professionals in Nigeria's development/health public health was estimated at over 5000. A cluster of professionals whose works relates to the supply chain of public health commodity was selected as the sampling frame [17]. This study used a target sample frame, though growing stands at 1,047 as at the time of this data collection in December 2017 [18]. This involved number of professionals in Nigeria who have identified as part of the International Association of Public Health Logisticians, IAPHL. The IAPHL is an association of public logistician from all over the world coming together to share knowledge, best practices and network. Sample size calculator was used to calculate the expected sample size. At a 95% confidence interval and P-value of 0.05, the estimated sample size was 281.

The questionnaire was shared on the listserv of the IAPHL and other smaller internet-based social network (Whatsapp, Telegram and LinkedIn) and opened for one (1) calendar month after which it was closed to further responses. At the end of one-month time horizon, (December 3, 2017, to January 2, 2018) a total of 200 valid responses were received and the questionnaire closed to further responses using the switch on the Google form. Following this stage, the data were harvested for onward analysis. We improve the response rate by assuring confidentiality and providing a concise introduction to the survey and how responses will affect a smoother supply chain. We also ensured that questionnaires were easy to use and understandable and only took 5-10 minutes of a participant's time. The permission and support of the administrator of the different platforms were also secured to give the process speed and credibility. This approach follows the strategy by Easterby-Smith *et al* [17]. On how to improve the response rate [17]. The data analysis combined SPSS version 25 and Microsoft Excel. With SPSS, we better managed data with case selection, file reshaping, and creating derived data. A metadata dictionary was stored with the data. Statistical analysis tasks performed with the base package include the generation of descriptive statistics, prediction of numerical outcomes, and prediction of identifying groups.

VII. RESULTS

Among the 200 valid respondents, 141 (70.5%) were males, and 59 (29.5%) were females (male: female; 2:1). The most frequent

age group was 31 – 40 (113, 56.5%) followed by 'above 41' (48, 24.0%) while the least value was seen for 21 – 30 (39, 19.5%). The number of respondents who had a maximum of 5 years working experience was 114 (57.0%), 57 (28.5%) had 6 – 10 years' experience while 14.5% had more than 10 years' experience (Table 1).

Majority of respondents were Health/Public health development professional (81, 40.5%) followed by 52 (26.0%) supply chain professional only, 49 (24.5%) were into the supply chain and health/public health development. There were 8 (4.0%) financial/business and project managers, 7 (3.5%) were regulatory and safety professionals while the IT profession had the least number of 3 (1.5%). Respondents were from various specialties including technical/executive officers (82, 41.0%), middle managers (59, 29.5%), consultants (26, 13.0%), senior managers (25, 12.5%) and regulatory/policymakers (8, 4.0%) (Table2).

Table 1: Demographics with years of experience

Parameter	Frequency	Percentage
Gender		
Male	141	70.5%
Female	59	29.5%
Age category		
21 - 30	39	19.5%
31 - 40	113	56.5%
41 and above	48	24.0%
Year of experience		
≤ 5	114	57.0%
6 – 10	57	28.5%
11 – 20	26	13.0%
>20	3	1.5%

Table 2: Respondents' profession and specialization

Parameter	Frequency	Percent
Profession		
Supply Chain Professional Only	52	26.0%
Health/Public Health/Devt Professional Only	81	40.5%
Supply Chain and Health/Public Health/Devt	49	24.5%
IT professionals Only	3	1.5%
Financial/Business and Project Mgt	8	4.0%
Regulatory and Safety Professionals	7	3.5%
Specialization		
Consultant	26	13.0%
Middle Manager	59	29.5%
Regulatory and Policy Maker	8	4.0%
Senior Manager	25	12.5%
Technical/Executive Officer	82	41.0%

A. KNOWLEDGE OF SUPPLY CHAIN WITH AN AWARENESS OF 3D PRINTING

The knowledge of respondents in the vaccine supply chain and level of awareness of 3D printing was examined. All (100.0%) Information Technology (IT) and regulatory and safety professionals had good knowledge of vaccine supply chain, 98.0% of supply chain and health/public health development, 92.3% of supply chain professionals, 91.8% of health/public health/development professional only while the least value of 62.5% was seen among financial/business and project managers. All IT professional had good (100.0%) awareness of 3D printing, 71.4% of regulatory and safety professionals, 67.3% of supply chain and health/public health/development professionals, 53.8% of supply chain professionals and 42.0% of health/public health/development professional only had good awareness of the use 3D printing in vaccine supply chain.

All consultants (100.0%) had good knowledge of the vaccine supply chain, but only 50.0% were aware of 3D printing in the vaccine supply chain. Most middle managers (91.5%) had good knowledge of the vaccine supply chain, and 54.2% had a good awareness of 3D printing. Knowledge and awareness of vaccine supply chain 3D printing were respectively 87.5% and 37.5% for regulators and policymakers; 92.0% and 64.0% for senior managers; and 91.5% and 53.7% for technical/executive officers. Based on the years of working experience, knowledge of vaccine supply chain was 92.1% for those who had a maximum of 5

years working experience, 89.5% for 6 - 10 years and 100% for those who had above 10 years' experience. On the other hand, working experience-based awareness was 55.3% for 5 years' experience, 35.1% for 6 – 10 years, 26.9% for 11 – 20 years and 66.7% for those who had over 20 years' experience (Table 2).

Table 2: Knowledge of supply chain with an awareness of 3D printing

Profession/Experience	Knowledge of Vaccine Supply Chain			Awareness of 3-D printing/Additive Manufacturing		
	Good Knowledge	Poor Knowledge	p	Good Awareness	Poor Awareness	p
Profession						
Supply Chain Professional Only	48 (92.3%)	4 (7.7%)		28 (53.8)	24 (46.2%)	
Health/Public Health/Devt Professional Only	74 (91.8%)	(8.6%)		34 (42.0%)	47 (58.0%)	
Supply Chain and Health/Public Health/Devt	48 (98.0%)	1 (2.0%)	**0.020**	33 (67.3%)	16 (32.7%)	**0.037**
IT professionals Only	3 (100.0)	-		3 (100.0%)	-	
Financial/Business and Project Mgt	5 (62.5%)	3 (37.5%)		5 (62.5)	3 (37.5%)	
Regulatory and Safety Professionals	7 (100.0%)	-		5 (71.4%)	2 (28.6%)	
Specialization						
Consultant	26 (100.0%)	-		13 (50.0%)	13 (50.0%)	
Middle Manager	54 (91.5%)	5 (8.5%)	**0.644**	32 (54.2%)	27 (45.8%)	**0.725**
Regulatory and Policy Maker	7 (87.5%)	1 (12.5%)		3 (37.5%)	5 (62.5%)	
Senior Manager	23 (92.0%)	2 (8.0%)		16 (64.0%)	9 (36.0%)	
Technical/Executive Officer	75 (91.5%)	7 (8.5%)		44 (53.7%)	38 (46.3%)	
Year of experience						
≤ 5	105 (92.1%)	9 (7.9)		51 (44.7%)	63 (55.3%)	
6 – 10	51 (89.5%)	6 (10.5%)	**0.372**	37 (64.9%)	20 (35.1%)	**0.012**
11 – 20	26 (100.0%)	-		19 (73.1%)	7 (26.9%)	
>20	3 (100.0%)	-		1 33.3%)	2 (66.7%)	

B. ACCEPTABILITY AND FEASIBILITY OF 3-D PRINTING/ADDITIVE MANUFACTURING IN NIGERIA VACCINE SUPPLY CHAIN

Participants were surveyed about the acceptability and feasibility of 3D printing in vaccine and supply chain in Nigerian. This survey was conceived to overcome the cold chain challenges in the country. Acceptability and feasibility were rated 86.5% among supply chain professionals only, 82.7% for health/public health/development professional Only, 91.8% for supply chain & health/public health development, 100.0% for IT professionals and regulatory & safety professionals, 87.5% for Financial/business and project managers. 3D printing recorded 80.8% acceptability by middle managers, 93.2 for middle managers, 87.5% for regulatory and policymakers, 92.0% and 89.0% for senior managers and technical/executive officers. Similarly, the feasibility of 3D printing was 100.0% among senior managers and minimum of 75.0% among regulators and policymakers. Among experienced professionals, 3D printing recorded acceptability and feasible (Table 3).

Table 3: Acceptability and Feasibility of 3-D printing/Additive Manufacturing in Nigeria Vaccine Supply Chain

	Parameter	*Acceptability*	*Feasibility*
Profession	**Supply Chain Professional Only**	86.5%	86.5%
	Health/Public Health/Devt Professional Only	82.7%	82.7%
	Supply Chain and Health/Public Health/Devt	91.8%	91.8%
	IT professionals Only	100.0%	100.0%
	Financial/Business and Project Mgt	87.5%	87.5%

	Regulatory and Safety Professionals	100.0%	100.0%
Specialization	**Consultant**	80.8%	92.3%
	Middle Manager	93.2%	88.1%
	Regulatory and Policy Maker	87.5%	75.0%
	Senior Manager	92.0%	100.0%
	Technical/Executive Officer	89.0%	81.7%
Year of experience	**≤ 5**	95.6%	88.6%
	6 – 10	100.0%	89.5%
	11 – 20	100.0%	96.2%
	>20	100.0%	66.7%

C. PREPAREDNESS TO TAKE UP NEW TECHNOLOGICAL INNOVATIONS IN NIGERIA VACCINE SUPPLY CHAIN

International political will was rated with the highest (96.0%) preparedness to take up new technologies/innovations in Nigeria vaccine supply chain followed by private sector involvement and collaboration (82.0%). Readiness in regulatory and policy was rated 76.5%, workforce know-how 73.0% while the national political will was rated 54.0%.

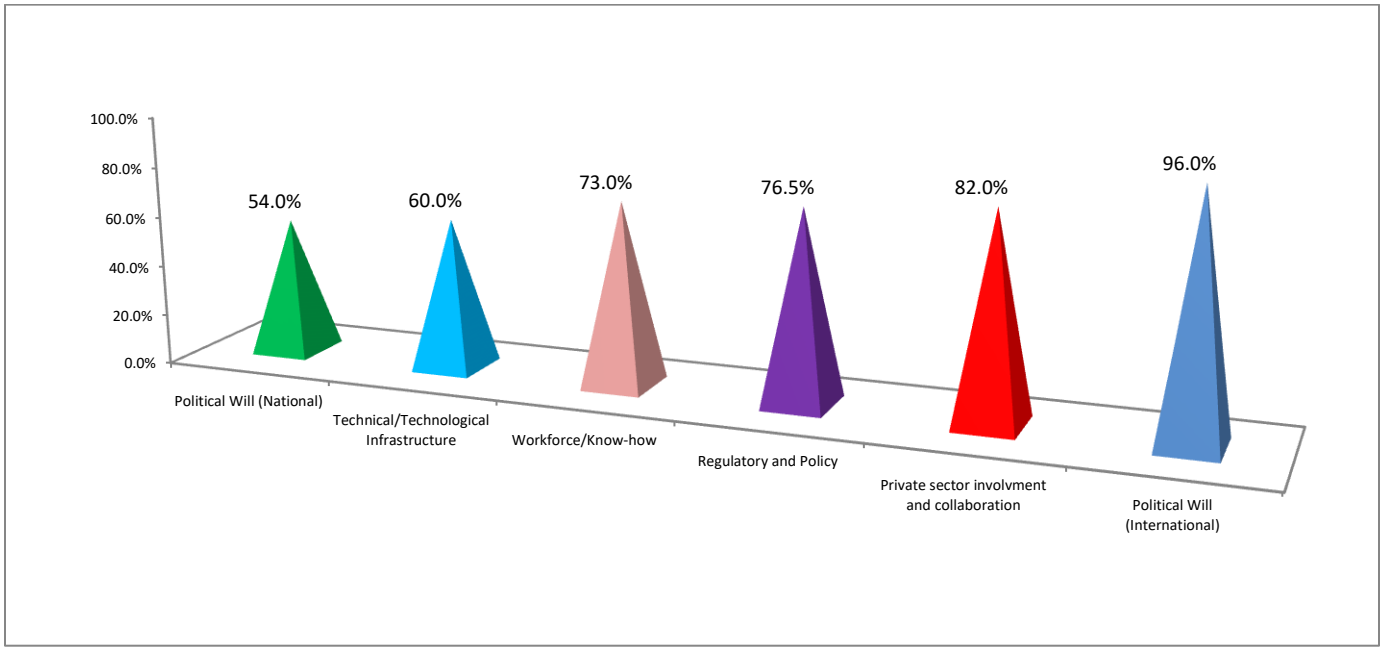

Figure 1: Preparedness to take up new technological innovations in Nigeria vaccine supply chain

VIII. DISCUSSION

The Nigeria vaccine supply chain is faced with critical bottlenecks which include temperature excursion, cold chain maintenance and the attendant issues of maintaining vaccine integrity across the supply chain network till the last mile. The study, therefore, takes a pragmatic approach to understand supply chain professionals' perspective regarding their awareness, acceptability, feasibility, and preparedness to take up innovations like 3D printing to optimize the vaccine supply chain and immunization coverage.

Majority of the respondents were males mostly of age group 31 – 40. Respondents were seen from different health/supply chain-related professions such as supply chain, health/public health,

information technology, financial/business, project management, regulatory and safety professionals. They were of various positions such as senior managers, middle managers, consultants as well as technical officers with work experiences ranging from 0 to above 20 years.

Good knowledge of the vaccine supply chain was recorded among respondents. All, except financial/project managers (62.5%) had over 90% good knowledge of vaccine supply chain. The level of awareness of the use of 3D printing in the vaccine supply chain was slightly high among respondents. Over 50% of respondents from each profession were aware of the use of 3D printing except respondents from financial/project management which only 42.0% were well aware of 3D printing in the vaccine supply chain. This finding can be attributed to the fair knowledge of Nigeria vaccine supply chain seen among them (only 62.5% had good knowledge whereas over 90% of other professions had good knowledge of vaccine supply chain). It was discovered that the knowledge of the vaccine supply chain was generally high, regardless of the number of years in service while 3D printing awareness was not so impressive among respondents. This unawareness might not be unconnected to the fact that the technology is not yet fully adopted in Nigeria vaccine supply chain. So, more awareness/training is needed for Nigerian supply chain professionals.

The level of acceptability of 3D printing into Nigeria vaccine supply chain was discovered to be very high regardless of profession, specialization or years of experience. Nigerian professionals are ready to accept 3D printing with acceptability range of 82.7% - 100.0%. Similarly, the use of 3D printing into the Nigeria vaccine supply chain was also rated very feasible in all specialization and professions. Campbell *et al.* [19] spoke on acceptability of 3D printing in supply chain that mass acceptability/adoption of 3D printing (distributed production model) could have far-reaching effects on the global economy—specifically, on global trade imbalances, as AM technology could enable countries that have traditionally imported most goods to reduce their reliance on foreign production. This outcome shows that Nigeria vaccine supply chain will be a perfect market for investors and manufactures as stated by Joann *et al.* [20] that 3D printing/AM technology represents a potentially valuable area for investigation and investment as companies consider ways to improve supply chain performance. Also, Drews [21] reported that "with today's slow down economic growth, companies' need to find other places to invest. Emerging markets, in the so-called developing countries, are predicted to grow twice to three times faster than countries like Europe or the US. As they are becoming the driver of global growth, they represent an exciting opportunity for investors". This approach will also help in saving lives, reducing stress as well as overcoming the challenges of cold chain and other bottlenecks to efficiency of vaccine supply chain in Nigeria. This finding confirms the report of Campbell *et al.* [19] that "as AM technology improves and becomes more suitable for more types of endues product production, AM may allow for the redesign of supply chains to better meet customer needs. Indeed, this may represent its most dramatic impact on the supply chain".

Respondents rated Nigeria vaccine supply chain politically, private sector involvement and collaboration, regulatory and policy, workforce knowhow and technical/technological infrastructure ready to take up new innovation/technology such as 3D printing.

IX. CONCLUSION

This study found that the majority of the community of experts had knowledge of the vaccine supply chain but had relatively fair knowledge/awareness of 3D printing. The overall acceptability and feasibility of 3D printing were generally high. Preparedness of Nigeria vaccine supply chain to take up 3D printing was rated high for international political will, private sector involvement and collaboration, readiness in regulatory and policy, workforce know-how and national political.

APPENDIX

Nil.

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Nil.

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