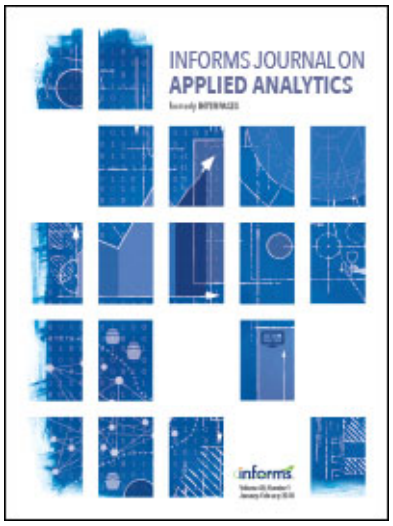

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THE FRANZ EDELMAN AWARD
Achievement in Operations Research

UN World Food Programme: Toward Zero Hunger with Analytics

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Abstract. Each year, the United Nations World Food Programme (WFP) provides food assistance to around 100 million people in more than 80 countries. Significant investments over the last decade have put planning and optimization at the forefront of tackling emergencies at WFP. A data-driven approach to managing operations has gradually become the norm and has culminated in the creation of a supply chain planning unit and savings of more than USD 150 million—enough to support two million food-insecure people for an entire year. In this paper, we describe three analytical solutions in detail: the Supply Chain Management Dashboard, which uses descriptive and predictive analytics to bring end-to-end visibility and anticipate operational issues; Optimus, which uses a mixed-integer programming model to simultaneously optimize food basket composition and supply chain planning; and DOTS, which is a data integration platform that helps WFP automate and synchronize complex data flows. Three impact studies for Iraq, South Sudan, and COVID-19 show how these tools have changed the way WFP manages its most complex operations. Through analytics, decision makers are now equipped with the insights they need to manage their operations in the best way, thereby saving and changing the lives of millions and bringing the world one step closer to zero hunger.

Keywords: WFP • zero hunger • humanitarian logistics • analytics • multicriteria optimization • Edelman Award

Introduction

Today, nearly 690 million people regularly go to bed hungry (FAO et al. 2020). One of 11 people do not have access to enough food, a situation exacerbated by the ongoing coronavirus (COVID-19) pandemic. Of the many measures in place to capture hunger and its severity, one of the foremost is the Integrated Food Security Phase Classification (IPC) developed by the Food Security Information Network (FSIN). In 2019, approximately 135 million people in 55 countries were facing crisis-level food insecurity (IPC classification 3 or higher) and in need of urgent food, livelihood, and nutrition assistance (Food Security Information Network 2020).

As a consequence of conflicts, climate change, and COVID-19, we are facing the greatest humanitarian crisis since World War II. The Global Humanitarian Overview 2021 (United Nations Office for the Coordination of Humanitarian Affairs 2020) predicted that a record 235 million people would need humanitarian assistance and protection in 2021, an increase of nearly 40% over 2020. This escalation is almost entirely because of the compounding effects of COVID-19, which has caused the deepest global recession since the 1930s.

One of the agencies responding to these humanitarian needs is the United Nations World Food Programme (WFP). WFP is the leading humanitarian organization saving lives and changing lives, delivering food assistance in emergencies, and working with communities to improve nutrition and build resilience. "For its efforts to combat hunger, for its contribution to bettering conditions for peace in conflict-affected areas and for acting as a driving force in efforts to prevent the use of hunger as a weapon of war and

conflict" (Norwegian Nobel Committee 2020), WFP received the Nobel Peace Prize in 2020.

In 2020, WFP assisted 115 million people in more than 80 countries (World Food Programme 2021b). On any given day, WFP operates 5,600 trucks, 30 ships, and nearly 100 planes to deliver food and other assistance to those in most need. In 2019, WFP delivered 4.2 million metric tons of food and USD 2.1 billion of cash and vouchers to the people it serves. By buying food at locations as close as possible to where it is needed, WFP saves time and money on transport costs and helps sustain local economies. Increasingly, WFP meets food needs through cash-based transfers that allow the people it serves to choose and shop locally for their own food.

Challenges

Humanitarian operations are complex to manage because they seek to address multifaceted problems with limited resources in a volatile operational environment. In addition to the sheer magnitude of the humanitarian needs, planning and managing humanitarian operations presents unique challenges:

1. **Demand volatility.** Although some humanitarian needs are seasonal (e.g., the Atlantic hurricane season or the El Niño drought), most of WFP's demand is volatile. Throughout the year, national conflicts may spread to different geographies, climate-related disasters may occur, and currency inflation may affect the affordability of basic foods, all resulting in sudden and significant increases in needs to which WFP must quickly respond.

2. **Access and security.** In many areas in which WFP is active, insecurity poses a serious threat to its operations: roadblocks, looting, ambushes, abduction, and even killing of humanitarian workers regularly impede or halt operations and may result in the loss of access to certain roads and locations. Delicate negotiations with governments, nonstate actors, and international NGOs are required to gain safe access to the population in need without compromising core humanitarian principles. Moreover, road infrastructure is often poor, especially in the impoverished and rural areas where WFP operates. Recurrent rainy seasons severely limit overall mobility and render large swathes of countries inaccessible by commercial means of transport for many months. WFP uses boats, all-terrain vehicles, and even helicopters and planes as last resorts to ensure food assistance is provided year-round. All this results in a complex supply chain with lengthy and dangerous food deliveries, requiring a high degree of flexibility in WFP's deliveries.

3. **Funding.** WFP's operations are funded entirely through voluntary contributions, with government funding as the principal source. Funding received is typically tied to specific operations or programmatic objectives, which might differ from where funding is needed the most. Because the funding amount is often uncertain and confirmed at the last minute, WFP must always be ready to respond quickly and utilize funds to meet the most pressing needs. In addition, WFP operations are rarely fully funded; average funding levels are 60%–70% of the total requirements. As a result, WFP has little flexibility in its operations management and requires constant (re)prioritization of its needs as new funding becomes available.

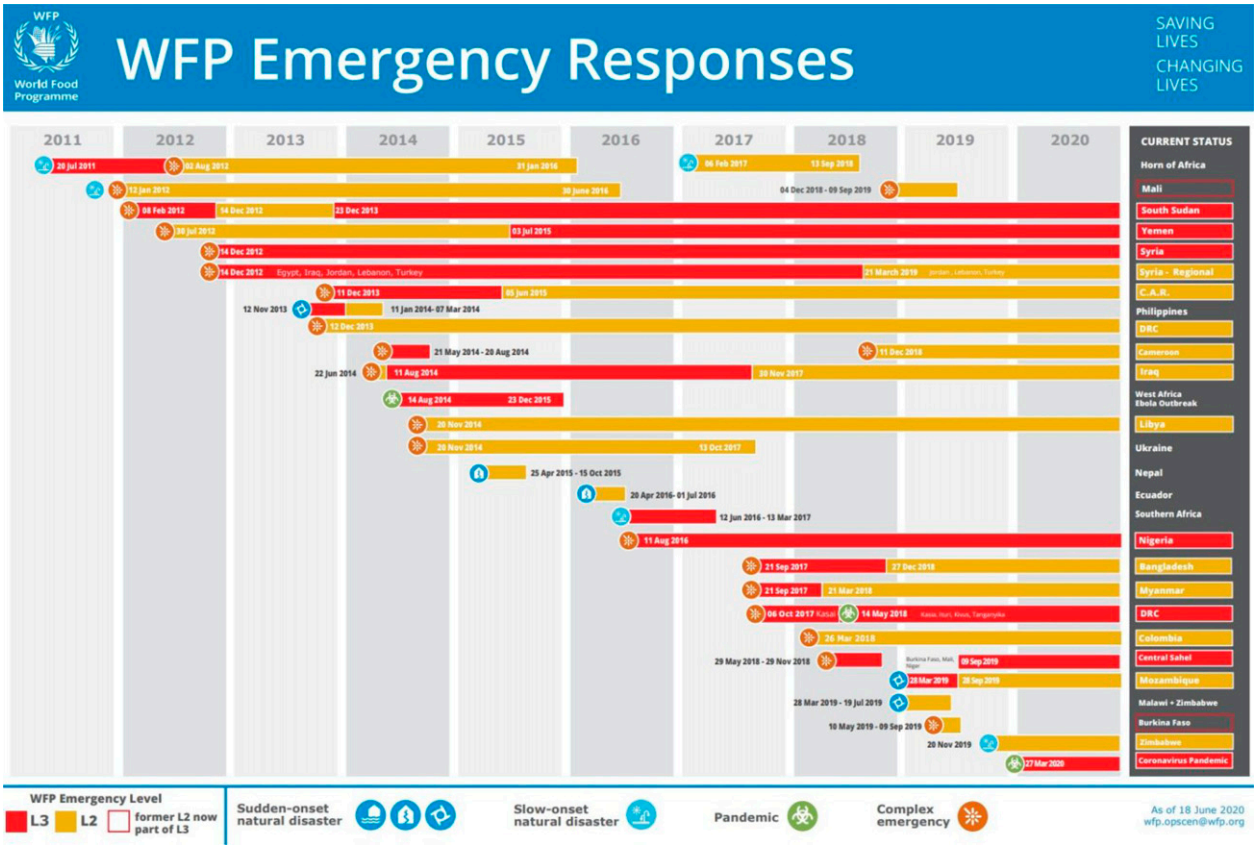
4. **Local economies and lead times.** To avoid undercutting the existing economies of targeted countries, WFP purchases locally as much as possible; in 2020, 80% of food was purchased in developing countries. When feasible, it also uses cash-based mechanisms (e.g., cash, vouchers, bank transfers, e-cards) to allow the people it serves to purchase their own food at nearby markets. However, when WFP needs to rely on external food supplies (e.g., when markets are disrupted by conflict or when the country has a significant food deficit), the upstream lead time is considerable (often up to several months), in particular for landlocked countries such as Chad and South Sudan. Pairing this with the volatile nature of WFP's demand and funding availability emphasizes the need for timely and agile planning of the entire supply chain.

5. **Protracted crises.** For most of its history, humanitarian assistance was dominated by short-term, postdisaster relief (e.g., Ethiopia famine, Nepal earthquake, Haiti hurricane). However, the last decade has seen a "new normal" of protracted crises, driven by conflict in the Middle East and Africa. Figure 1 shows the timeline of Level 2 (L2) and Level 3 (L3) emergencies. L2 emergencies are those that require substantial regional coordination and cooperation to ensure an effective response. L3 emergencies are those with such urgency, scale, and complexity that they overwhelm the capacities of the local and regional teams and therefore require significant corporate attention and extraordinary support.

6. **Decentralized operations.** WFP is renowned for its footprint in the countries it serves, and each of its 80+ country offices (COs) has an autonomous decision-making process. This is one of the organization's strengths and enables it to provide agile response; however, it also presents some challenges, because each country may be using a different mix of tools and systems to manage its operations. Additionally, some scarce resources are shared across COs (e.g., port capacity or unrestricted funding), which means managing WFP's global supply chain requires aggregation, alignment, and prioritization between these independent operational plans.

7. **Data and technology.** In this digital age people are constantly collecting data. This is a great asset to humanitarians because it allows for evidence-based decision making; however, it presents major risks, because

Figure 1. Increasingly Protracted Nature of WFP Emergencies Since 2011



data can come from diverse and often conflicting sources and can therefore be interpreted in different ways. This unclarity can be paralyzing, slowing down the humanitarian response and putting lives at risk. Additionally, the lower maturity of technological infrastructure in many low-income countries impedes obtaining reliable real-time information, which is the norm for logistic companies in high-income countries. This means that industry solutions to support operations management can rarely be deployed without significant reconfiguration; so building new solutions from the ground up is typically easier. Finally, data protection is critical (in particular for personal information) because the recipients of humanitarian assistance may have fled persecution in their country of origin.

The combination of these factors forces humanitarian decision makers to constantly evaluate and replan their operations as needs evolve and new information becomes available. Therefore, monitoring and understanding each operation, anticipating what is expected to happen next, and optimizing the limited resources available to the organization is critical.

To that end, WFP has been embracing the power of analytics. Engineers and mathematicians have taken a leading role in supporting complex operations, using analytics as an enabler to strengthen the integration between functional areas, augment visibility on WFP operations, and find concrete ways to maximize their efficiency and effectiveness. By collaborating with universities and private sector partners, WFP has been able to turn its data into actionable insights.

In this paper, we discuss WFP's journey over the last decade to adopt analytics for its operations management. The journey started with early explorations of descriptive and prescriptive analytics with universities between 2008 and 2014, followed by active deployment of (mostly manual) prototypes from 2012 to 2017, and finally culminated in the development and institutionalization of automated solutions between 2017 and 2021. The next section covers three main innovations adopted by WFP, followed by impactful applications for three emergencies in particular: Iraq, South Sudan, and the COVID-19 response. Finally, we reflect on the transformational change that the organization has undergone following this gradual adoption of new analytical tools and management practices and describe some of the ongoing research to further improve them.

Analytics at WFP

Good operations management starts with end-to-end visibility. It is critical to stay on top of the volatile

context in which WFP operates, understand the impact of new developments on food security, and ensure that WFP's response adequately addresses the needs of the affected population. Although such visibility should be heavily rooted in WFP data, leveraging outside intelligence to anticipate external factors that could significantly impact WFP operations (e.g., COVID-19 projections, macro-economic trends, political developments) is also critical. Facilitated by technical solutions such as the Supply Chain Management Dashboard (SCM-D) (Sithole et al. 2016) and the DOTS platform (World Food Programme 2019b), planners merge internal with external intelligence to obtain a 360-degree view for each operation.

Once WFP has good operational visibility, it needs to make smart decisions: making sure resources are used optimally and the best plans are in place to respond to anticipated issues. For this purpose, state-of-the-art approaches were developed to support the cross-functional design and planning of WFP operations, such as the award-winning Optimus tool (Dutch Coalition for Humanitarian Innovation 2018).

By improving cross-functional cooperation and rooting decisions in fact-based analyses, WFP is now able to respond more rapidly to operational issues and reach more people with its limited available resources. In this section, we discuss three analytical innovations that have been at the core of WFP's transformation:

1. The SCM-D, a platform using descriptive and predictive analytics to provide end-to-end visibility on WFP operations;
2. Optimus, a web-based application using prescriptive analytics to design optimal food baskets and supply chain plans for any WFP activity; and
3. DOTS, an online data integration platform used to automate and synchronize complex data flows across multiple data systems, allowing tools like the SCM-D and Optimus to be deployed at scale.

End-to-End Visibility with the SCM-D

Humanitarian operations are constantly evolving, which comes with a high risk of misalignment. Each functional area involved in managing operations may be planning based on different data and assumptions, which can cause confusion and lead to delays and suboptimal decisions. To address this issue, WFP invested in the SCM-D (Sithole et al. 2016), which presents a unified and holistic view of each operation and is validated and approved by each functional area. It is paired with a decision-making forum where senior management comes together to evaluate the status of complex emergencies and decides on the next steps.

Some examples of key information provided by the dashboard include recent changes to the operational context (e.g., security issues, new household assessments), latest implementation plans (planned beneficiaries and rations), availability of food commodities (and where they are in the supply chain), and funding shortfalls to be remedied. Although initially focused on descriptive analytics, the dashboards incrementally moved to predictive and prescriptive analytics, automatically flagging potential issues to different business functions (e.g., delayed shipments, gaps in the monthly distribution, expiring stock) and suggesting concrete actions (e.g., dispatching stock from a hub to a field warehouse, replenishing a commodity for a cluster of countries, requesting an extension of a donor's contribution deadline). The SCM-D projects the expected food availability over time against the planned distributions, indicating the resources available to fulfil the demand. As a result, upcoming shortfalls can be easily identified and remedied in time.

WFP first piloted the approach during the 2012 Sahel drought, bringing together key functions at WFP local, regional, and headquarters levels, all looking at the same unified view of the complex regional emergency. It significantly improved WFP's agility to respond to new information and insights; therefore, in 2013, executive management decided to make this integrated approach mandatory for all L3 emergencies through a decision-making forum called the Supply Chain Working Group.

During the first few years, the dashboards were built using Excel and PowerPoint. Experienced planners would manually collect the necessary information from WFP systems, process it in Excel (including cleaning and integration), and then validate it thoroughly with local teams and technical experts before presenting it during meetings of the Supply Chain Working Group. To reduce the lead time for preparing dashboards, which could take up to a week of full-time work, and to ensure any country could access its insights (not only for L3 emergencies), WFP partnered with Palantir to create an automated, online version: the Operations Management Dashboard. In 2018, it was made available to all WFP staff worldwide on the DOTS platform. Now anyone in WFP can access a near-live view of each operation, with many options to aggregate (at a regional or global level) or drill down to specific activities, commodities, and locations.

In 2020, with the advent of COVID-19, the need arose for a decision-making forum that spanned the breadth of WFP's operations (including wider concerns such as staffing and nonfood items). Under the leadership of WFP's senior director of operations, the concept of a Supply Chain Working Group, which focused on specific emergencies, evolved into the COVID Operational Task Force (OTF). All regional and divisional directors met biweekly to review the status of WFP's global pandemic response based on cross-

functional dashboards and analyses. Their focus was to understand and address any gaps or obstacles in WFP's operations during the critical months of the pandemic. Because of the success of the approach, it was formalized in December 2020. Starting in 2021, a monthly global OTF was put in place and will remain active after COVID. The Application Case Studies and Impact section includes more details on this topic.

Optimization with Optimus

Building on the strong operational visibility achieved with the dashboard, the next step was to make the right decisions. WFP had seen the benefits of operations research through its supply chain partners, including TNT Express who won the Edelman Award in 2012 with support from Tilburg University (Fleuren et al. 2013). Working closely with students from Tilburg University (De Bresser et al. 2012, Veersma et al. 2013, Peters et al. 2014, Badenbroek et al. 2016, Wolter et al. 2016, Maragno et al. 2020, Poos et al. 2020, Stienen et al. 2021) and the Georgia Institute of Technology (Wade et al. 2008, Alvarenga et al. 2010, Singh et al. 2014), WFP explored different use cases for predictive and prescriptive analytics (e.g., network design, vehicle routing, food basket design, price forecasting, machine learning) across its global, regional, and country-specific operations. Although several tools and insights culminated from these investments and initiatives, the one we highlight in this section is the Optimus tool (Peters et al. 2021).

Optimus is an online decision support system that helps WFP optimize its operations from an end-to-end perspective through an innovative combination of network flow and diet optimization models specifically adapted to deal with the challenges we describe in the Challenges section. It simultaneously optimizes the design of the food basket (i.e., which commodities to distribute) and the sourcing and delivery plan (from suppliers to final delivery points). This makes it possible to identify the best way to provide food assistance given a large variety of operational constraints (such as funding and lead times) and programmatic objectives (such as nutritional value and local investments). It is helping decision makers determine which commodities to put in a food basket such that beneficiaries receive the calories and nutrients they need while simultaneously designing an efficient and realistic supply chain to deliver that basket. This data-driven approach ensures WFP operations are as cost-effective as possible and allows decision makers to easily evaluate what-if scenarios.

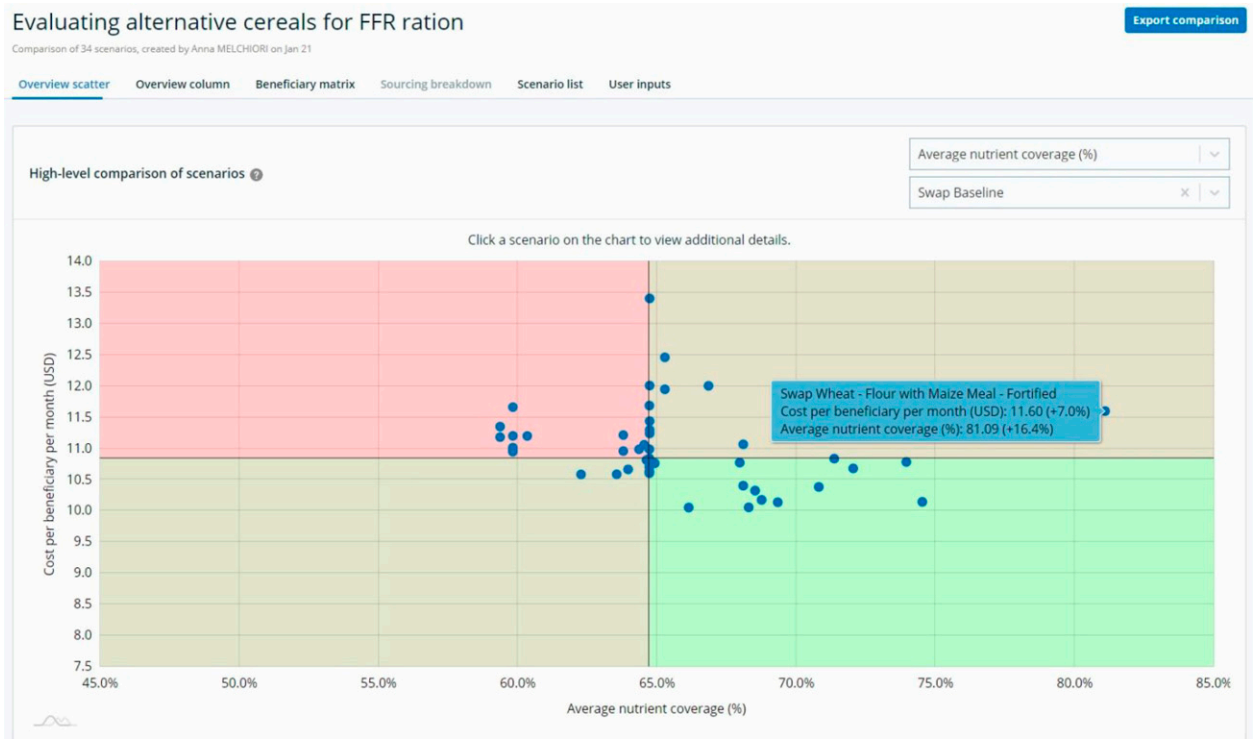
The mathematical model at the basis of the tool is an extension of a mixed-integer, capacitated, multicommodity, multiperiod network flow problem, where the typical demand inputs are replaced with a variable food basket (governed by nutrition-related variables and constraints). The model is solved in a few seconds up to a few minutes even for large instances using the Computational Infrastructure for Operations Research (COIN-OR) mixed-integer linear programming solver COIN-OR Branch and Cut (Github 2021). For the seminal paper on the Optimus model and tool, please refer to Peters et al. (2021). Reflecting the multifaceted problems that WFP decision makers seek to address, the model is often used for rapidly generating hundreds of what-if scenarios or exploring Pareto-efficient solutions. These models are instantiated with an objective function that minimizes cost with constraints that reflect programmatic and operational objectives, such as meeting a specified nutritional or caloric requirement, an average or maximum lead-time requirement, local procurement targets, and many others. For example, a Pareto-efficient frontier of solutions may be generated by minimizing the cost per beneficiary and varying the specified percentage of the daily nutritional requirement being met (with each solver run having a particular percentage of the nutritional percentage expressed in a constraint). Figure 2 illustrates Optimus in operation, helping to identify more cost-effective rations by slightly changing their food composition.

The first prototypes of Optimus were developed in 2014 by students from Georgia Tech and Tilburg University. Since 2015, Optimus has been used to support L3 and complex emergencies—with savings of more than USD 50 million confirmed to date. A dedicated team of supply chain planners continually seeks to identify optimization opportunities for major operations by running analyses in close collaboration with cross-functional experts across the organization. This interactive approach allows analysts to identify concrete changes that improve the operation, such as altering food baskets, increasing local procurement, or switching to cash-based transfers.

Initial analyses required intensive, manual data collection and processing before optimization could be used to explore alternative configurations for a WFP operation. To ensure the model could be applied more widely across the organization, the development of an automated, web-based tool was initiated in 2016. Following best practices in agile development and human-centered design, WFP has been making continual investments to ensure the entire process (from ingestion of corporate data to the detailed visualization of optimal plans) performs as smoothly as possible, is fully in line with evolving business processes, and is usable by a wide range of WFP users (most of whom have no background in data science).

Optimus is currently being rolled out to all WFP regional bureaus and country offices with the help of the UPS Foundation, which has been funding the project since 2018 and has supported its change management

Figure 2. Commodity Swap Analysis Using Optimus



Notes. This chart shows the output of an automated analysis computed in Optimus for a general food distribution activity. Each point represents a detailed implementation plan where a commodity in the official food basket has been swapped with an alternative one from the same food group, leaving the rest of the ration as is. The chart is centered on the baseline scenario (i.e., the official transfer of the activity) and simultaneously compares scenarios with respect to the cost per beneficiary per month (y axis) that WFP would incur to implement the solution and the average coverage as a percentage (x axis) of the targeted beneficiaries' nutritional requirements. Scenarios falling in the bottom-right quadrant represent more cost-effective rations than those in the current implementation.

based on experiences with similar projects within the UPS Foundation (Holland et al. 2017). As of early 2021, more than 40 Optimus power users are spread across WFP's regional bureaus, representing key functional areas such as logistics, procurement, nutrition, and resource management. These power users support their regions with optimization, paving the way for a country-level rollout in 2021–2022.

Data Integration with DOTS

The tools described in the previous sections rely on a large amount of data from different parts of the organization to allow for a 360-degree coverage of each operation. Although much of this information is available, it is typically not ready for cross-functional analysis. Data must be sourced from more than a dozen disparate systems, each of which manages its data in different ways, for example, different formats, technologies, update frequencies, and master data. This means that before data can be used in any analysis, they must be processed heavily to ensure they align with the other sources.

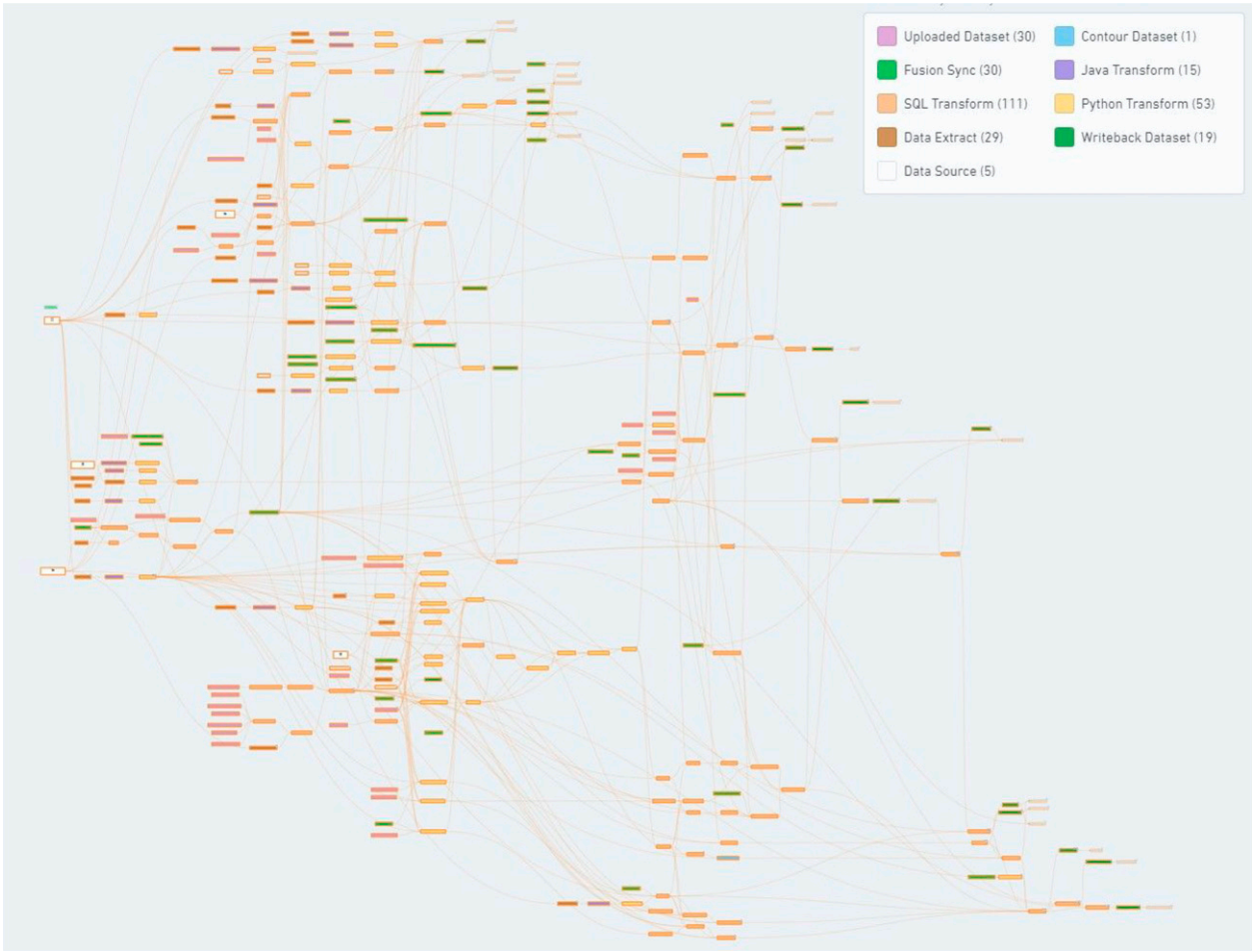
As an example, suppose WFP wants to evaluate the operational performance of a specific country. To do so, it must analyze the cost and nutritional effectiveness of the food basket distributed in that country. First, it must identify the composition of the food basket by reviewing demand management systems. Once WFP knows which commodities the food basket contains, it must link that information to supplier contracts to understand the usual sourcing locations. For a complete picture of the costs of the food basket, the next step is linking to procurement systems to obtain the latest pricing information at those locations and to the logistics database to find the actual transport costs from there to the beneficiary. To evaluate the nutritional score of the food basket, the information must be linked to the nutritional databases. Finally, some beneficiaries in the country under review may receive cash-based transfers rather than food. To evaluate the cost-effectiveness of a cash-based transfer, WFP must link to the systems storing local market data about available commodities and prices. Despite the wealth of available information, the disconnected nature of the data systems made conducting these types of cross-functional analyses difficult and time-consuming.

For many years, this fragmented data panorama within WFP meant that creating a new SCM-D or running an Optimus analysis would be preceded by at least a week of data gathering, cleaning, and validation, all requiring a thorough understanding of many data systems and taxonomies. This made the prototypes difficult to bring to scale; therefore, they were used predominantly by a team of engineers in WFP's headquarters to support the top 5–10 emergencies. To ensure these innovations could be used more frequently and by a larger group of users, WFP needed to invest in data management.

In 2019, WFP announced a partnership with Palantir (World Food Programme 2019b), a Silicon Valley–based company. In conjunction with the company, WFP deployed a new solution, known as DOTS and built on Palantir's Foundry software, to address the data integration challenge that the organization faced. Leveraging the platform, WFP was able to easily establish data connections to any platform and implement complex algorithms to automatically process and integrate these data streams. The first DOTS use case focused on addressing all the data required to run Optimus, which had to be sourced from more than a dozen different systems. This resulted in the data pipeline represented in Figure 3, consisting of more than 260 unique tables that are automatically synchronized and updated nightly. By accessing the latest information from each separate source and then integrating it through a comprehensive and thoroughly validated business logic, all data are ready for consumption by Optimus and other tools as needed.

DOTS has now become the corporate data integration platform; any tool that requires extensive processing or the integration of different data streams is being migrated there. For WFP-managed databases close-to-live connections are being established. For example, data from WFP's SAP system is updated every 15 minutes, ensuring accurate views on critical operational information such as the position of stock, the availability of funding, and the status of new purchases. A corporate object model is being established to further

Figure 3. (Color online) Data Pipeline for Optimus Consists of 260 Linked Data Sets, Which Are Updated and Synchronized Daily



facilitate the interactions between functional areas and support the integration of disparate data streams. Finally, the platform offers strong data access management functionalities, which is helping WFP to keep sensitive data secure and protected.

Application Case Studies and Impact

This coordinated, proactive, and data-driven approach to managing operations has resulted in a wide range of benefits to WFP. In this section, we first highlight seven of the key benefits.

1. **Agility**. In Mozambique, analytics enabled WFP to respond faster to cyclone Idai in 2019. Analytics helped establish a single source of truth for the operational status during the wake of the cyclone, supporting the overall coordination and optimization of the humanitarian response to 1.85 million affected people (World Food Programme 2020e).

2. **Anticipation**. At a global level, analytics helped identify an increasing disconnect between supplier capacity and operational demand for fortified foods. A cross-functional working group was established where capacity utilization is prioritized and optimized based on global needs (World Food Programme 2020a).

3. **Scale-up**. In Yemen, analytics enabled WFP to gradually and responsibly scale up the operation from assisting 3 million people in 2014 to more than 12 million people in 2020. Optimization of distribution strategies and supply chain network setups maximized the amount of people reached with the available budget (Peters et al. 2021).

4. **Coverage**. In South Sudan, analytics enabled WFP to better leverage the riverine network, providing a food lifeline to beneficiaries that would otherwise have been cut off because of the rainy season. This expansion and redesign of the delivery network not only allowed WFP to reach more people but also resulted in savings of USD 100 million in 2019 (World Food Programme 2019a).

5. **Cost-effectiveness**. In Iraq, analytics helped identify more cost-effective food baskets. Simultaneously optimizing the composition of the ration and the supply chain strategy reduced monthly operational costs by 12% without compromising the nutritional value of the basket. The optimized basket was distributed for more than two years, resulting in savings of more than USD 25 million (World Food Programme 2017, 2018; Peters et al. 2021).

6. **Operational continuity**. Since the start of the Syria crisis in 2011, analytics has helped minimize the number of stockouts by improving operational visibility, reducing supply chain lead times by 40 days, and optimizing the complex delivery network (providing savings of USD 2 million), and food basket savings of greater than USD 25 million (World Food Programme 2015, 2018).

7. **Transportability**. The humanitarian community has acknowledged WFP's performance in these areas, and since 2018 WFP has increasingly been requested to support governments and agencies (e.g., World Health Organization (WHO), Global Fund, Bill & Melinda Gates Foundation) with analytical projects (World Food Programme 2020c). For example, WFP developed the analytical control tower that is driving the COVID-19 response cell in WHO Geneva, where the agencies work together to ensure global availability of health products (World Food Programme 2020d).

We next provide an in-depth analysis using three specific success cases: Iraq's food basket optimization (2015), South Sudan's network redesign (2018), and the global COVID-19 response (2020).

Optimizing Food Baskets in Iraq

Years of conflict have impeded Iraq's economic development. Since 2014, the occupation of the Islamic State of Iraq and the Levant (ISIL) in Iraq has resulted in the displacement of more than three million people. Two years later, when the Iraqi security forces (ISF) launched a military offensive to regain control, fighting increased insecurity, rolled back development, and exacerbated vulnerabilities. Many Iraqis sought refuge in neighboring countries and in Europe. Beset by violence, social disruption, and economic hardship, thousands of Iraqi families were left in desperate need of food assistance.

Overall security in Iraq has improved since the defeat of ISIL at the end of 2017, although significant challenges remain—including political and security transitions, economic instability, and social unrest because of rising unemployment, eroded public services, and persistent low standards of living. The humanitarian situation is still precarious in many conflict-affected areas. Iraq's poverty rate is 22.5%, it ranks 120 of 189 countries in the 2019 Human Development Index (United Nations Development Programme 2020), and it still houses 1.39 million displaced Iraqis and 247,440 Syrian refugees. Some families report secondary displacements, because they were forced to return to camps due to security conditions and the lack of job and livelihood opportunities in their home regions (World Food Programme 2021c).

WFP has been operating in Iraq since 1991; in 2014, it initiated emergency operations to assist hundreds of thousands of Iraqis forced from their homes by violence. Mass displacements from major Iraqi cities, such as Mosul and Ramadi, caused WFP to increase its activities to reach about 1.5 million people per month in all 18 governorates, including hard-to-reach areas. WFP assisted people by providing monthly family food parcels for those with access to cooking facilities, food vouchers that could be redeemed at local shops, and ready-to-eat food, known as immediate

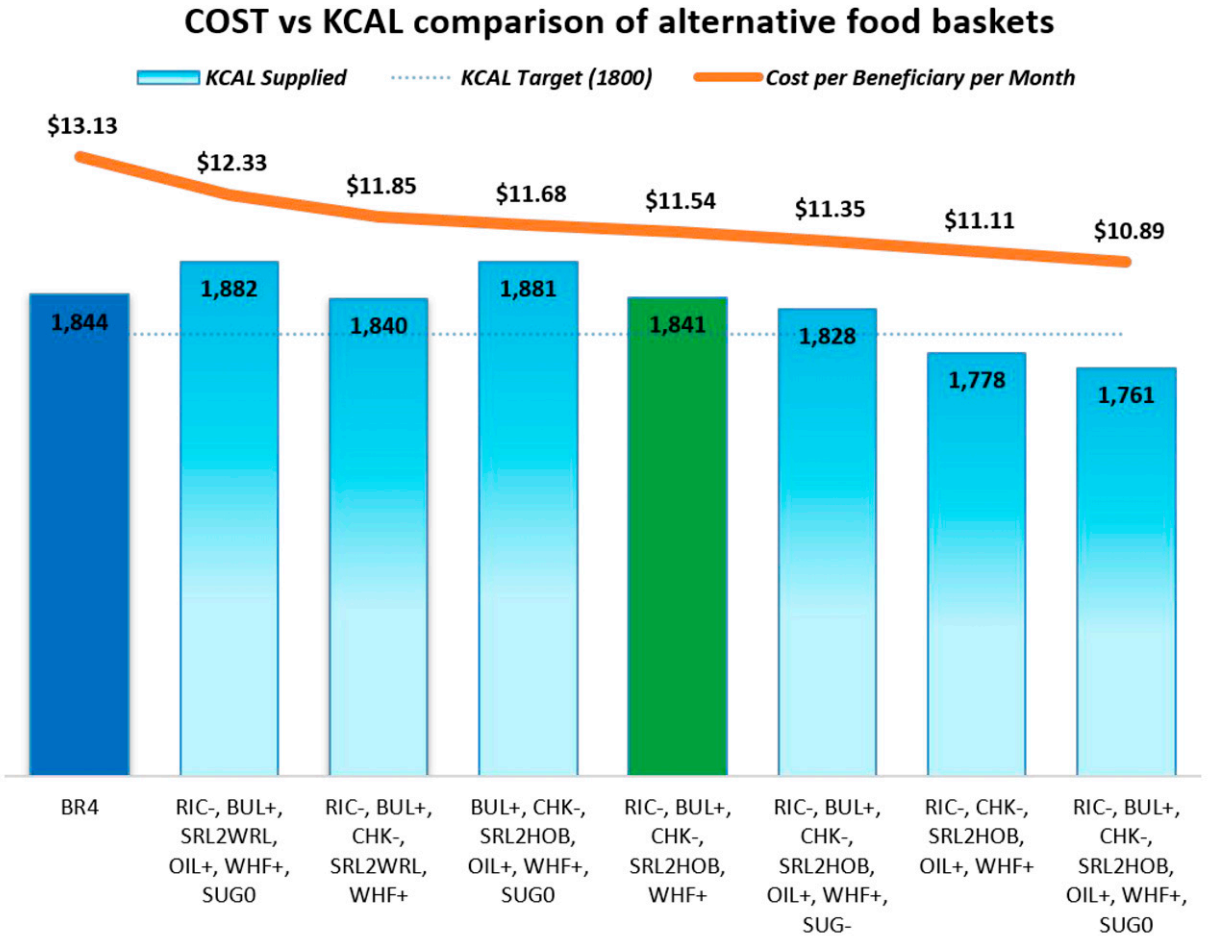
response rations, that provide a family of five with food for three days.

WFP's operations in Iraq often face funding shortfalls; therefore, the operation's design must be as cost-effective as possible. In October 2015, Iraq's Country Office requested optimization support to redesign its food basket for different levels of funding, allowing it to supply as many kilocalories as possible from the donations that it receives. The analysis shared in this paper is an extract from Peters et al. (2021).

Optimization experts worked intensively with the local staff to collect data and identify operational constraints regarding issues such procurement, logistics, transfer modalities, and beneficiary preferences. Once they had a good understanding of the constraints, they ran hundreds of analyses using Optimus to identify alternative designs that could improve the performance of the operation and validated them thoroughly with the local experts. This deep collaboration resulted in giving the local team a strong sense of ownership of the final outcomes, resulting in a rapid implementation of the final recommendations.

Figure 4 shows one of the main deliverables to Iraq's management—the recommendations for Iraq's family food parcel (FFP), which WFP was supplying to half a million Iraqis every month. The first column represents the latest official food basket (BR4), supplying 1,844 kilocalories daily at a cost of USD 13.13 per beneficiary per month. Each subsequent column is an optimized basket that uses different interventions (e.g., commodity swaps, ration adjustments) to improve the cost-effectiveness of the operation. Iraq officially adopted the food basket represented by the green column, supplying 1,841 kilocalories (only 3 kilocalories

Figure 4. Comparison of Alternative Food Baskets Identified by Optimus for Iraq's Family Food Parcel (FFP)



Notes. Kilocalories (kcal) and cost per beneficiary per month are compared for each option. The acronyms beneath each column indicate the change in the food basket with respect to the original ration (BR4). RIC, rice; BUL, bulgur wheat; WHF, wheat flour; SRL, split red lentils; WRL, whole red lentils; WIB, white beans; CHK, chickpeas; HOB, horse beans; OIL, sunflower oil; SUG, white sugar. A + or − denotes an increase or decrease in the current ration size, respectively. A 0 denotes a removal of the commodity, whereas a2b denotes a swap from commodity a to commodity b keeping the same ration size. Ration size increments are predefined and based on commercial packaging types for that specific commodity. The fifth option from the left has been implemented in practice, representing a cost reduction of 12% while supplying only 3 kcal less.

less) and 69% of the beneficiaries' overall nutrient gap (across 11 nutrients) at a cost of USD 11.54 per beneficiary per month (12% less expensive). The optimized food basket, which was distributed throughout 2016 and 2017, represented total savings of more than USD 25 million, and the changes in commodities and ration sizes, compared with those in the original food basket, generated positive feedback from the beneficiaries.

Redesigning Delivery Networks in South Sudan

Only two years after South Sudan's independence in 2011, a civil war broke out that has since been causing widespread destruction, death, and displacement. Approximately 1.47 million people are internally displaced and another 2.2 million are refugees in neighboring countries. Despite a current fragile state of peace, intercommunal violence remains prevalent. The country is one of the least developed countries in the world, ranking 185 of 189 according to the Human Development Index (United Nations Development Programme 2020). Recent flooding and COVID-19 have exacerbated already catastrophic food-insecurity levels across the country, with almost seven million people (60% of the population) struggling to find enough food each day (World Food Programme 2021d), and parts of the country facing famine-like conditions.

It is therefore not surprising that WFP has one of its largest operations in South Sudan, distributing food as well as cash-based transfers through various programs, including emergency food assistance to save lives and prevent famine, assistance to refugees, school meals, and nutrition programs. WFP reaches approximately five million people every year, requiring almost one billion USD for its operations in South Sudan alone. However, the operation is typically only funded at around 60%–75%, implying that not all the critically needed food assistance can be provided, resulting in ration cuts for highly food-insecure populations in need. Optimization of operations is therefore crucial to ensure that the limited resources can have a maximal impact—feeding more with less.

South Sudan is frequently nicknamed "WFP University" because of its high operational complexity. As a landlocked country, roughly 300,000 metric tonnes (MT) of food are delivered every year through three principal overland corridors (Sudan, Ethiopia, and Kenya/Uganda). Poor road infrastructure (almost no roads are tarmacked) is particularly challenging during the rainy season, leaving most of the country inaccessible via truck for over half a year. During this period, the Sudd (one of the world's largest swamps) may extend to 130,000 square kilometers, a fifth of the country's surface area. For this reason, food must be prepositioned up to nine months in advance, and WFP uses multiple modalities to deliver food to thousands of deep field locations: by truck, canoes or barges, airdrop or airlift, and even using all-terrain vehicles. Numerous roadblocks, checkpoints, and militia groups render the process of delivering food dangerous and lengthy. Figure 5 shows a schematic overview of South Sudan's supply chain network.

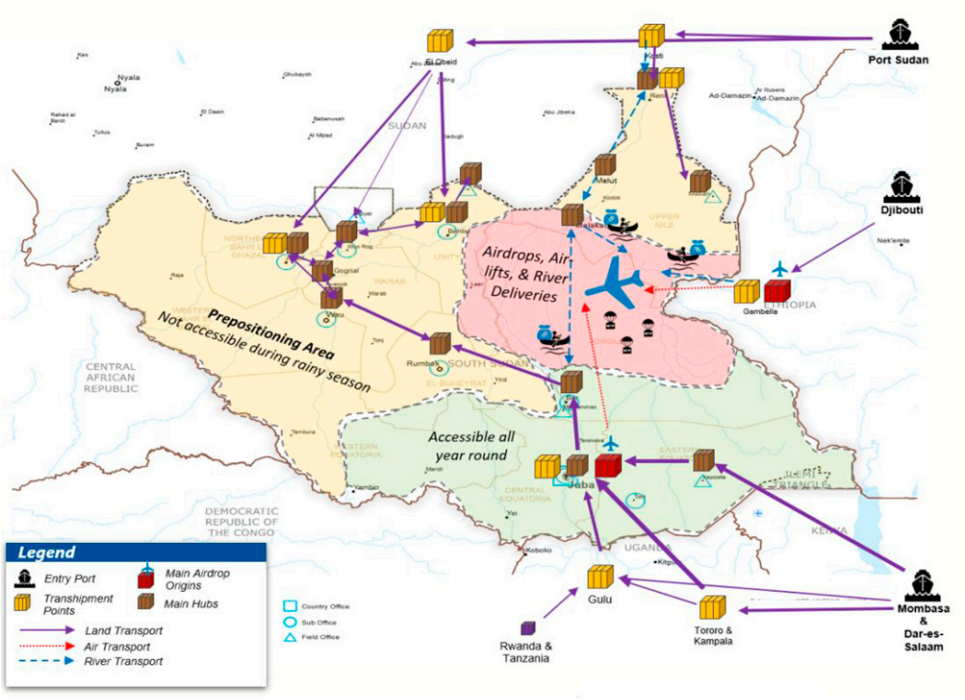
This high operational complexity thus presents numerous opportunities to optimize the sourcing and delivery network. Since 2019, combined cost savings of over USD 100 million have been achieved through two major improvements: (1) by redesigning the downstream delivery network to reduce costly airdrops and (2) by determining and implementing an optimal upstream corridor utilization.

First, the number of airdrops (which cost up to five times more than road deliveries) was reduced significantly by analyzing hundreds of locations that were traditionally served by air and replacing air deliveries with other means of transport—either by prepositioning food via trucks during a brief dry-season window in which roads are accessible or by using the riverine network. Both approaches require year-long planning and advanced analytics combining geospatial data, road networks, weather patterns, food assistance requirements, population movements, and river navigability data, which were collected during assessments especially designed for this purpose, to determine the types of boats and barges that could navigate the various rivers at any given time. These efforts have resulted in record levels of prepositioning and river deliveries, reducing airdrops from around 65,000 MT in 2018 to around 22,000 MT in 2019. Every MT that is not prepositioned in time must be flown in at an additional cost of around $2,000 per MT. Figure 6 shows the riverine network with major locations that were traditionally accessible only via air in the Greater Upper Nile region.

This would not have been possible without adequate donor support. To preposition such large amounts of food in a given calendar year, WFP requires around 70%–80% of its funding for food operations to be available by February at the latest. Analytics have helped WFP with its communication with donors by providing the right facts, which has resulted in a change in the share of funding that WFP has received during the period of October–February from just 17% in 2017 to 63% in 2020. In addition, these analyses have enabled the South Sudan operation to receive exceptional advance financing of approximately USD 100 million each year through WFP's internal advance financing mechanisms. Humanitarian operations are reliant on donors, who appreciate when operational plans and funding requests are backed up with clear analytics (Thompson et al. 2015).

Second, the upstream delivery network was improved, using the methodology of the optimization software Optimus. Given the preposition requirements

Figure 5. (Color online) Overview of the Complex Delivery Network Required to Reach Beneficiaries in South Sudan



at the various locations, food supply availability, cost variables for sourcing, transport, storage, handling, seasonal fluctuations, access constraints, and donor restrictions, WFP determined an optimal corridor allocation for each food commodity and subsequently implemented this allocation. This optimization has resulted in a significant increase in the utilization of the northern corridor (Sudan), in part because of a much higher recommended sorghum purchase from Sudan, which the model identified as the most efficient way to resupply most hubs.

Analytics has resulted in over USD 100 million in cost savings and has also enabled WFP to better leverage the riverine network, providing a food lifeline to beneficiaries who would otherwise have been cut off due to the rainy season. To accomplish this, WFP had to reinstate barge deliveries from Sudan to South Sudan for the first time in 2019 because river transport of humanitarian goods between the two countries had largely stopped following independence in 2011. This breakthrough has significant implications on regional stability and has contributed to peace-building activities and economic development (World Food Programme 2019c).

Responding to the COVID-19 Pandemic

For WFP, responding to emergencies is second nature. The COVID-19 pandemic disrupted the world as we knew it, taking a heavy toll on human lives and economic activities. Its rapid global spread threatened to affect millions of people already made vulnerable by food insecurity, malnutrition, and the effects of conflict and other disasters (World Food Programme 2021a). To minimize the impact of the pandemic, WFP adapted its planning and operations to ensure people would continue to receive the assistance they need. This required significant changes to WFP's operating model, both for its internal operations and for the services it provides to the larger humanitarian community. In both cases, analytics were at the center.

Global Coordination Through the Operational Task Force

On March 11, 2020, WHO declared the COVID-19 outbreak as a pandemic. This raised WFP's operation to a L3 emergency that, according to WFP's policy, automatically activated the Supply Chain Working Group approach. Because of the unprecedented complexity and geographic scope of the emergency, analytics teams across the organization were called on to provide inputs and insights as new data emerged.

To coordinate their efforts, the Operations Cross-functional Analytical Group (OCAG) was established. Leveraging the DOTS and SCM-D tools, the OCAG was able to connect data sources from each functional area, obtaining a clear end-to-end global overview. Because of the rapidly changing environment, overlaying these automated views with human perspectives became critical.

Figure 6. Riverine Network with Major Locations That Were Traditionally Accessible Only via Air in the Greater Upper Nile Region

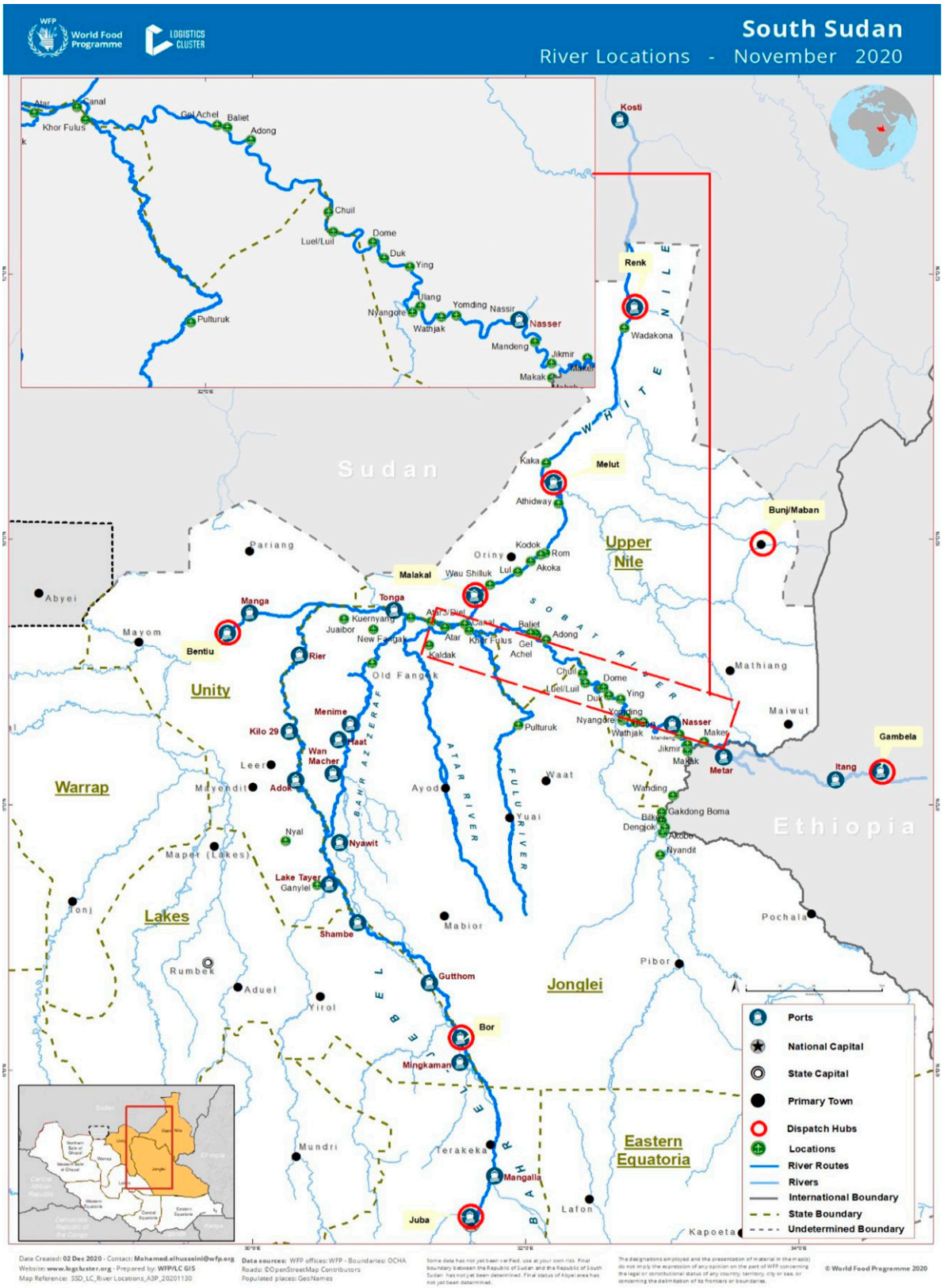
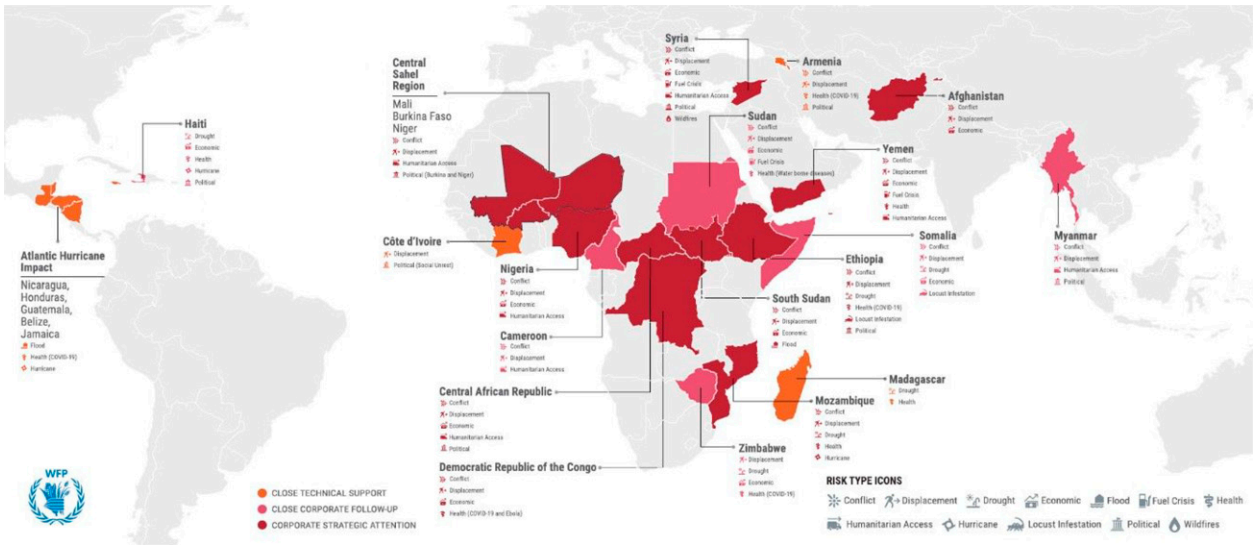


Figure 7. (Color online) Prioritized Countries (and Drivers for Prioritization) as an Example of Input Provided for the Global Operational Task Force



Each week, the OCAG brought together experts from key functions, such as programme, fundraising, resource management, nutrition, and supply chain, presented the latest global overview, and allowed the experts to supplement the automated data flows with their latest qualitative insights. This approach brought a unique level of organizational alignment and allowed all involved parties to gain a thorough understanding of global developments and the resulting impact on WFP operations. Focusing on WFP's response to the pandemic, the OCAG monitored:

1. **Operating environments.** Changes in the economic situation, host government restrictions, geopolitics, and macro-economic indicators across the globe, assessing their potential impact on WFP operations.

2. **Requirements.** Food-insecurity trends, latest needs assessments, the most likely scale-up plans, changes in transfer modality, and the resulting impact on global WFP requirements.

3. **Donor activities.** The funding behavior of donors, potentially affected by the pandemic and possible de-prioritization of humanitarian funding, tracking if funds are made available in advance and more flexibly as requested.

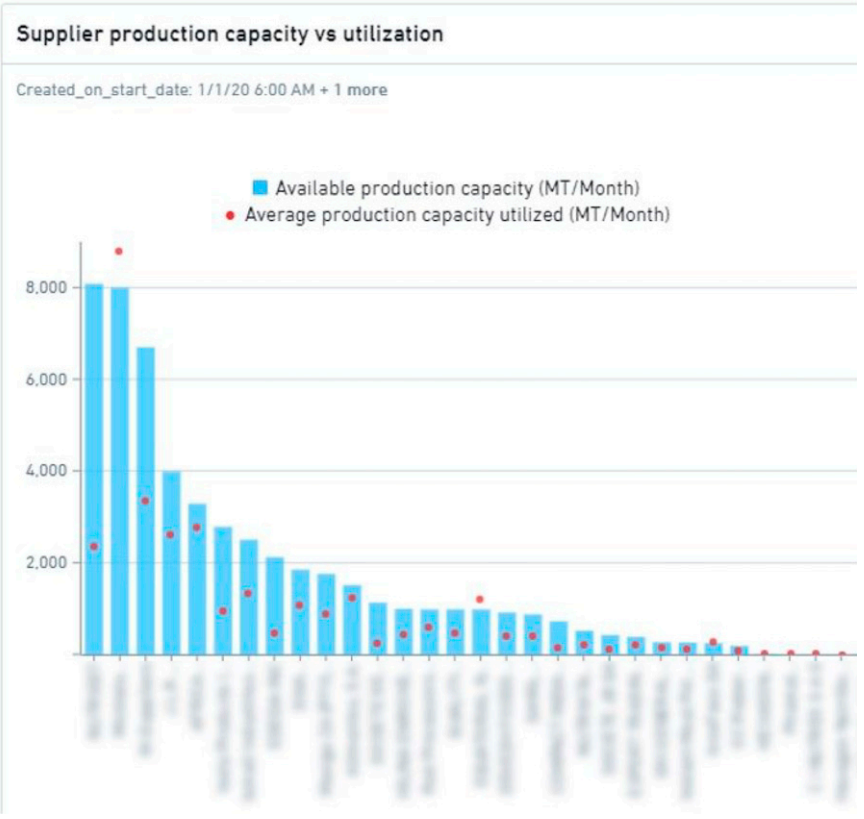
4. **Supply chain.** Border closures, trade restrictions, supplier capacities (particularly suppliers of nutritious food particularly affected by the pandemic), (ocean) transport capacities, national supply chains, private sector and market behavior, ongoing procurements and shipments, and the prepositioning status of safety stocks.

5. **Implementation.** Operational performance, food and cash distributions, and beneficiaries reached compared against target figures.

Each week, the latest insights from the OCAG were presented during the COVID-19 OTF, a meeting chaired by the senior director of operations and attended by all regional directors and divisional directors. By monitoring the above areas, the OCAG was able to flag operational issues and potential areas of concern (e.g., need increases in certain regions/countries, implementation issues, operations not reaching beneficiary targets, spikes in procurement prices, supply chain delays) and recommend remedial actions (e.g., reserve funds, surge in deployment of staff, rerouting of cargo, replacement of commodities). Countries most in need of support are flagged (Figure 7), after which directors discuss available solutions and prioritize scarce resources (e.g., unallocated funding and staff).

Thorough cross-functional planning was critical in the context of this global task force. For example, the manufacturers of fortified products (i.e., food enhanced with additional micronutrients to better prevent or treat malnutrition) were particularly affected by the pandemic, which led to a significant reduction in the global supply capacity of these products. At the same time, WFP's need for these products had never been higher as food security worsened across the globe. To balance the reduction in supply with the increasing needs and ensure that the people with the most critical needs were not affected negatively by the situation, WFP had to (1) prioritize the demand of the various countries, (2) maximize the utilization of the supplies available globally, and (3) satisfy the demand with alternative products when and where possible. Planning at this granularity on a global scale required a continuous end-to-end picture of the situation via the DOTS platform and SCM-D. Figure 8 shows a live dashboard

Figure 8. (Color online) DOTS-Based Dashboard Monitors the Utilization of Scarce Supplier Capacity for Fortified Foods (Supplier Names Are Anonymized)



monitoring the utilization of scarce capacity for a key supplier of fortified products, giving procurement teams clear visibility on remaining opportunities to increase the supply.

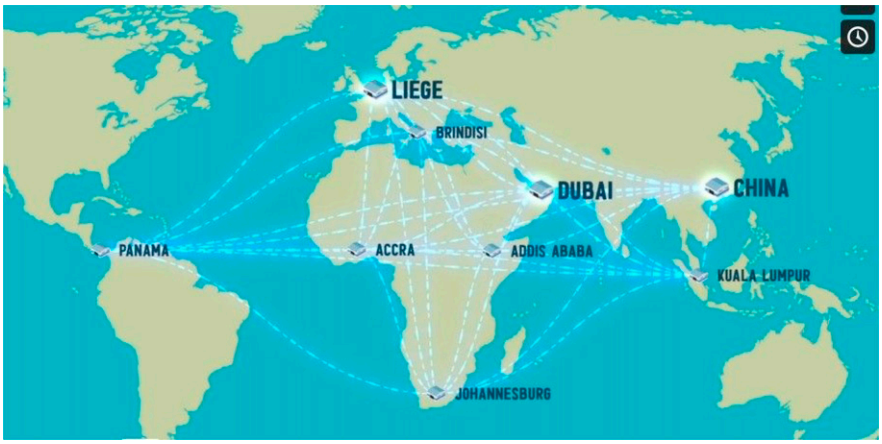
The OCAG and COVID-19 OTF were instrumental in maintaining a food lifeline to people that rely on WFP's support to avoid hunger and malnutrition. With the pandemic came unprecedented restrictions to access (e.g., lockdowns, travel bans) and significant health risks to both WFP staff and its beneficiaries. Despite these operational challenges, more than 500 staff were deployed to 44 operations most in need. Clear and data-driven planning scenarios enabled WFP to adapt to COVID-19–imposed measures and replace the regular school feeding activities with take-home rations for seven million school children in 45 countries. Visibility on food price developments and transport markets allowed WFP to respond by switching procurement locations and investing in local and regional markets where needed, mitigating against supply chain delays caused by slowdowns in the global transport market. In the first half of 2020, 553,000 MT of food were sourced in countries of operation—an increase of 17% compared with the same period in 2019. WFP was able to sustain operations and scale up to meet new needs, reaching a record high of 115 million beneficiaries in 2020 (up from 97 million beneficiaries in 2019). This would have been impossible without analytics teams working around the clock to stay on top of the latest developments and provide data-driven solutions to allow for the strategic prioritization of corporate resources (from funding to staff) under the leadership of senior management.

Medical Cargo Delivery Using the Common Services Control Tower

Transporting thousands of tons of life-saving cargo across the globe is never an easy logistics task, but with supply routes impaired by COVID-19, these shipments became even more challenging for humanitarian agencies. In 2020, WFP stepped up to the mark by giving agencies access to its logistics expertise, allowing organizations to use WFP's transport network to move COVID-related cargo anywhere in the world through a common services initiative (World Food Programme 2020b). Vital items such as personal protective equipment (PPE) and ventilators were moved through WFP's network of strategic consolidation hubs (Figure 9), ensuring that cargo was sent to where it was needed between April 2020 and January 2021.

The biggest technical challenge was to rapidly and consistently integrate and harmonize various sources

Figure 9. (Color online) Eight Strategic Consolidation Hubs Allowed WFP to Offer Transportation Services to the Wider Humanitarian Community Through a Common Services Initiative



of data for the overwhelming number of items, partners, countries, and hubs. To organize and manage requests from scores of organizations for delivery to more than 150 countries, WFP created a system it called the Control Tower. Building on the SCM-D approach and developed using the DOTS platform, it allowed WFP to organize and automate the distribution of essential health and humanitarian items around the world, by consolidating all necessary information into one centralized platform.

The Control Tower allows WFP to process each partners' service request timely and efficiently, giving end-to-end visibility of the cargo's location at any moment and facilitating a more agile planning and decision-making process. It also sends out alerts for actions that must be taken to prevent delays in the supply chain execution, ensuring that each step of the implementation is addressed in a timely manner.

Partners enter their transport request through an online portal, the Emergency Service Marketplace, and provide as much information as possible to guide WFP's operations. Logisticians from the eight hubs can review these requests in the Control Tower to check their validity and plan for the delivery. Discrepancies in volume or weight are automatically identified and flagged by the system. If everything is in order, the hubs accept the cargo, and the partner receives a link to track the shipment on the Emergency Service Marketplace. All teams involved (e.g., clients, hubs, partners) have full visibility on the request and are given an estimated time of arrival so they can plan the cargo reception accordingly. Figure 10 shows an example of a dashboard providing visibility to WFP logisticians.

Among other donors, Takeda was a key sponsor on this initiative, making it possible to rapidly develop and deploy the solution (World Food Programme 2020d). To date, the Control Tower has processed more than 2,000 service requests to 173 countries via more than 1,000 cargo flights. This complex logistics operation has allowed the transport of nearly 150,000 cubic meters of health and humanitarian cargo to where it was needed the most. By July 2020, WFP was reaching more countries in the world than any commercial passenger airline at that time.

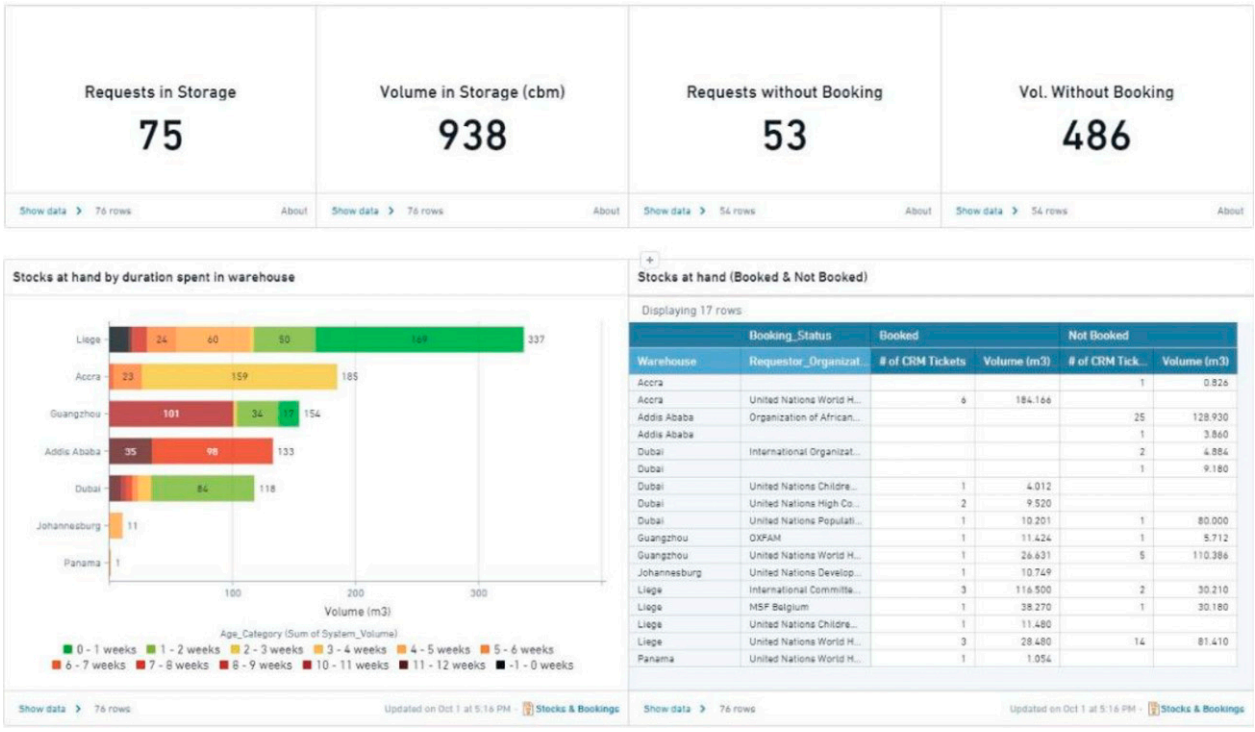
WFP has a long history of providing humanitarians with access to its logistics network and responding to some of the worst humanitarian crises; however, it had never operated in an environment with a crisis of this scale. WFP's proven expertise in logistics and investment in analytics and data integration, combined with the dedicated capacity of hundreds of logistics staff working around the clock, were key to forming a successful response to this unprecedented crisis. The solutions developed to support WFP's common services in 2020 are now being expanded to become a single point of entry for future service provision requests.

Future Research

In the previous section, we described the wide range of benefits that analytics, from descriptive to prescriptive, has brought to WFP operations. To continually improve the solutions we developed and to explore new use cases, our research collaboration with universities is ongoing. In this section, we describe three main areas of continued investment.

To better optimize WFP's operations, the Optimus model is continually being refined. A simplified version of the model is being studied as part of several academic courses at Massachusetts Institute of Technology, Tilburg University, and University of Amsterdam. Currently the research with Tilburg University focuses on exploring extensions of the Optimus model to make it more robust against uncertain parameters (e.g., price, capacity) and allow for nonconvex objective functions (e.g., to account for economies of scale).

Figure 10. (Color online) DOTS-Based Dashboards Provide Easy Visibility of Current Stock and the Status of Partner Bookings



With the University of Amsterdam, WFP is exploring the use of machine learning to improve the optimization models and infer constraints from data (University of Amsterdam 2020).

Having seen the benefits of operations research to inform its own food assistance, WFP is increasing its investments in operations research to also inform policy-level decision making. In conjunction with Johns Hopkins' Center for a Livable Future, CapGemini, and Tilburg University's Zero Hunger Laboratory, WFP is exploring the use of optimization to inform longer-term planning of national food supply and demand to provide for diets that meet objectives related to climate, affordability, health, and nutrition in the best way possible and are in line with consumer preferences (Semba et al. 2020, de Pee et al. 2021). The project, Environment, Nutrition and Health Analytics for National, Consumer and Emergency diets (ENHANCE), builds on WFP's experiences with "Fill the Nutrient Gap" analyses (Bose et al. 2019) and aims to guide low- and middle-income countries in their transition to more sustainable and equitable food systems.

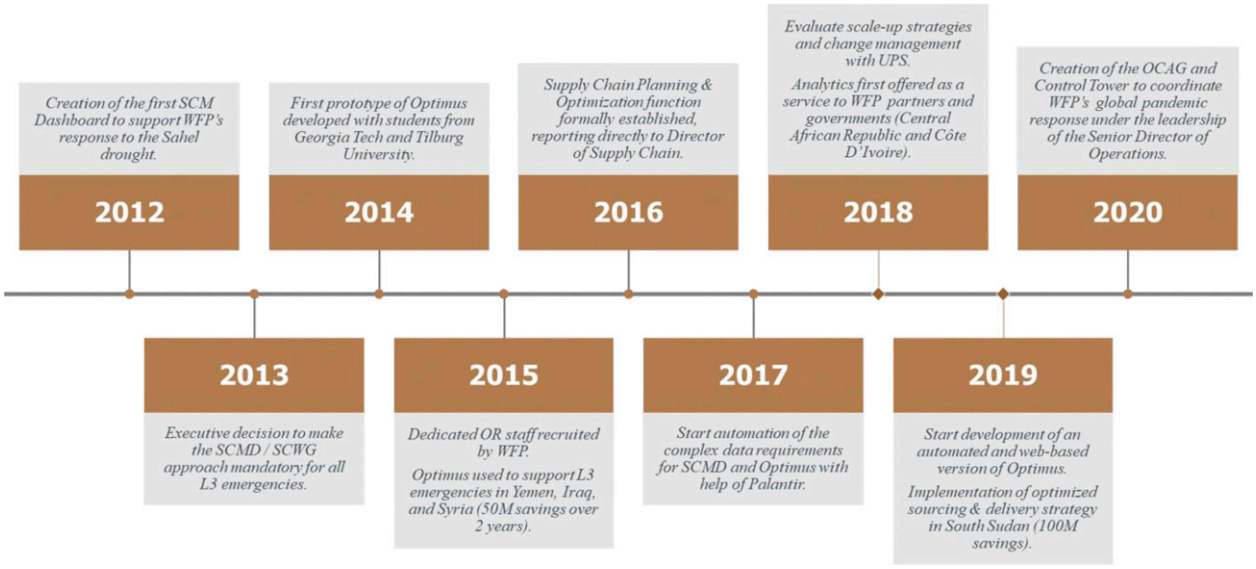
WFP is also taking operational visibility to the next level by investing in predictive analytics. With its main corporate data systems now being integrated into DOTS, a wealth of historical information has become easily accessible. This internal intelligence asset is currently being complemented by various external data sources, setting the stage for the development of statistical models to allow WFP to predict with more accuracy future events both within and outside of the organization; examples include port congestion, funding issues, reduced commodity supplies, and deteriorations in macro-economic or security situations impacting inflation and currency availability. With this, WFP will be better able to anticipate shocks in the operating environment and potential supply chain issues and thus increase its capability to respond quickly and effectively.

Reflection on the Journey

The work we describe in this paper reflects WFP's paradigm shift and increasing reliance on analytics to manage its operations. Building on prototypes and explorations with universities such as Georgia Tech and Tilburg University, which started more than a decade ago, this work has gradually fostered an awareness of the potential of analytics across senior management in the organization. WFP's response to the Sahel drought in 2012 proved a turning point because the first SCMD and Supply Chain Working Group were instrumental in managing the emergency in an agile and efficient way. Less than a year later, WFP's executive director signed a memorandum making the approach mandatory for every L3 emergency.

As WFP started expanding on this cross-functional and data-driven approach to operations management, it established a new unit in 2016: the supply chain

Figure 11. (Color online) High-Level Timeline Shows WFP's Gradual Adoption of Analytics to Support Operations Management



planning and optimization unit and a newly established job title of a supply chain planning officer, reporting directly to the director of supply chain. Starting as a small team of engineers and data scientists using analytics to support complex emergencies, it grew to a staff of 20–25 people in 2020, a third of whom have majored in operations research. With the help of UPS Foundation, WFP has started placing supply chain planning officers in WFP's regional bureaus and in the offices of large countries, ensuring easy access to advanced analytics capacity for each WFP operation.

The wider humanitarian community has also recognized WFP's increased capability in the area of analytics. In 2018, WFP was first requested to support nongovernmental organizations in the Central African Republic with supply chain visibility and optimization. Operations research experts from WFP worked closely together with World Vision International, the French Red Cross, and The Global Fund to develop custom analytical solutions to help them track and manage inventories for critical health products treating Malaria, human immunodeficiency virus, and tuberculosis (World Food Programme 2020c). Since then, WFP has provided similar support in many other countries, encouraging governments and humanitarian agencies to adopt analytics to support their own operations management and decision making.

In 2020, with the world beset by the COVID-19 pandemic, analytics proved pivotal to ensure continuity for WFP's global operations—both for its own food-assistance activities and its wider support to the humanitarian community through the Common Services initiative. Through the COVID-19 Operational Task Force and OCAG, senior management met weekly to reflect on the latest trends and developments related to food insecurity, travel restrictions, and caseload evolutions. The approach was considered so successful that it has been institutionalized in a global OTF that will stay in place beyond the pandemic.

Tackling the world's most complex problems requires state-of-the-art solutions. WFP has spent more than a decade (Figure 11) with numerous partners on developing innovative tools and applying them to its largest operations and to those of its partners, thus generating diverse and significant impact. By setting up processes (such as working groups and operational meetings) that provide a platform for the use of analytics and establishing a dedicated function and unit to maximize their impact, WFP has undergone a transformative change that allows it to benefit from analytics at scale.

Significant investments over the last decade have put planning and optimization at the forefront of tackling emergencies, and a data-driven approach to managing operations has gradually become the norm. Planning and analytics have helped WFP maintain a food lifeline to those in need, from Yemen to South Sudan and from Syria to the global COVID-19 response. The tools developed provide end-to-end decision support for each WFP operation, making it possible to rapidly evaluate trade-offs to identify the most efficient and effective course of action. WFP's adoption of analytics has enabled a more agile response to complex emergencies and natural disasters, fostered the reestablishment of trade routes between Sudan and South Sudan, and resulted in efficiency gains upwards of USD 150 million—enough to support two million food insecure people for an entire

year. Through analytics, decision makers are now equipped with the insights they need to manage their operations in the best way, thereby changing the lives of millions and bringing the world one step closer to Zero Hunger.

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