A Software Factory in the Cloud for Pandemics and other Disasters – Initial Results and Future Directions

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Abstract: **Pandemics such as COVID-19 and other disasters in this age require a wide range of cyber-physical solutions such as web portals, mobile apps, IoTs, robots and drones. These solutions need to be customized for different geographical locations with different capabilities and should be produced quickly and at massive scales to meet the specific demands of the disasters. To complicate matters further, several government policies and industry guidelines regulate the deployment and use of such solutions. It is virtually impossible to handcraft the needed solutions individually and manually. A factory model is needed to rapidly build highly customized solutions very much like the auto factories that build millions of highly customized cars to satisfy needed safety requirements. In the same vein, this paper presents initial results from a software factory in the cloud that has produced a Smart Global Village (SGV) with more than 700 smart hubs for 130 countries that span 12 sectors, including disaster management. These highly customized smart hubs, created by using the SPACE Factory in less than 20 minutes per hub, also collaborate with each other that leads to highly creative B2B collaborations at global level. The paper discusses initial results from creating the SGV sandbox by using a factory model and outlines future research directions.**

Keywords: Disaster Resilience Planning; Pandemic/Disaster Resilience; Smart Cities/Communities; Pandemics and Disasters; Factory4Disaster Planning; SPACE4Disastr Planning

I. Introduction And Key Challenges

COVID-19 and other disruptions have taught us that we as a society need to address the following major challenges to assure that *no one is left behind:*

- *Help save lives* of the citizens and healthcare workers
- *Help manage and control the threat* quickly, if possible
- *Rebuild and transform* the affected sectors for resilience

Table1 displays the starting point of our vision – it illustrates how the three goals can be satisfied by four types of services (Administrative & Policy Services, End-User (Citizen) Services, Project Management Services and Training Services). The core idea is based on a series of discussions with a few communities in Pennsylvania, Maryland, Michigan and North Carolina. Our current work with the United Nations [23-27] and awareness of current literature on this topic [5, 12,13, 17-20] has helped us to refine this table. The *Services* mentioned in Table1 could be enabled by digital technologies such as AI, big data, blockchains, facial and voice recognition, cognitive analytics, robotics, IoTs, 3D printing, 5G networks, and others. Examples of these services are smart apps that could take vital readings of COVID infected patients and thus save lives of nurses, resource allocation algorithms to assure adequate medical supplies for patients, and innovative gamifications for resilience planning and training of *Small to Medium Business and Towns (SMBTs).* This table represents a high level sample of an otherwise large table.

TABLE1: Sample Solutions for the COVID-19 Pandemic

Needed Services	**Save Lives**	**Manage & Control**	**Rebuild & Transform for Resilience**
End-User (Citizen) Services	Computer vision apps that use AI & Big Data to analyze pictures of a crowd and determine the violations of social distancing and wearing masks policies. Mobile clinics that empower communities to provide care anywhere	Citizen apps that use AI to help the citizens with better self diagnostics, recovery and other essential services. Citizen apps that improve social distance alerts & quarantine monitoring	Citizen apps that provide low cost but high impact services to *SMBTs* for resilience and continuity. A Digital Transformation Advisor that uses 3D printing to suggest more resilient work-place settings
Administrative Services and Policies	Smart Apps to take vital statistics to save nurses lives, policies that make wearing masks and social distances mandatory	Use of the feedback control theory to diminish the spread of COVID [20] and to regulate the resources	Better management and regulation of robots for resilience in the manufacturing cells that require close personal contact
Project Management (PMGT) Services	The WHO (World Health Org.) Pillar1 and Pillar9 [28] that specify PMGT services to save lives.	The WHO Pillars 2, 3, 6 & 7 [28]) services that help improve management and control	The WHO Pillar 8 [36] can be gamified to help in Digital Transformation of SMBTs
Training Services	Gamified guidebooks of do's and don'ts for crises to save lives [14]	Training for policy makers to manage & control the threat	Course to teach SMBTs Digital Transformation & Resilience

The services in each cell of Table1 suggest solutions that may need to be modified for different geographical locations (e.g., rural areas in developing countries) and should be produced quickly and at massive scales to meet the specific demands of the disasters. To complicate matters further, several government policies and industry guidelines regulate the deployment and use of some solutions. Given the interest of academia and industry, it is possible that thousands of point solutions will be developed focusing on different aspects of the challenges. However, most of these solutions will *not* be integrated with each other and will possibly have limited use due to the information overload. According to a small business owner in Michigan -- " I run a small business and do not have the time or the background to evaluate thousands of apps that could be of value to me".

II. Proposed Solution Approach -- A Software Factory

Given the aforementioned challenges, it is virtually impossible to handcraft the needed integrated solutions individually and manually. A factory model is needed to rapidly build highly customized solutions rapidly very much like the auto factories that have built millions of highly customized cars that integrate multiple technologies to satisfy needed safety requirements. We are proposing a computer aided planning, engineering and management approach that uses a "factory" model because factories have generated millions of highly customized cars that have nicely integrated safety and other regulations in *every* car. Specifically, we are interested in a *software factory,* as illustrated in Exhibit1.

Simply stated, a software factory assists in producing software or cyber-physical components (*the artifacts*) according to end-user requirements *through* an assembly process [1]. Such factories should be able to produce the needed artifacts at a massive scale rapidly if needed. The concept of software factories has been around since the 1960s [2, 3, 4] and has evolved over the years from handwritten process diagrams to the Google Repository in 2020 that maintains *all* source codes from 25,000 employees of Google [1]. In addition, different views of software factories have emerged, e.g., use of AI on quality assurance only [10]. Most software factories so far have been developed for specialized needs of large organizations such as NASA, Airforce, IRS, Google and others [1-4]. For example, Google Repository is only available to Google employees [1]. We are interested in a software factory for a very large number of Small to Medium Business and Towns (SMBTs) around the globe that quickly need location and topic specific artifacts for pandemics, disasters and other emergencies. SMBTs do not have adequate financial and technology resources and need assistance throughout the plan-do-check cycle.

Our vision is to use the SPACE (Strategic Planning, Architecture, Controls & Education) Toolset, introduced in Exhibit1, as a "Factory" to rapidly generate needed artifacts. Specifically, we are requiring that the solution services *must* be: a) low cost (i.e., affordable by SMBTs) but high impact, b) location and topic specific, c) integrated with each other, and d) smart so that they can acquire new knowledge automatically for better performance in the future. As a test-case, we have used the SPACE factory to populate portions of a Smart Global Village (SGV) – a sandbox with more than 700 'smart hubs' for 130 countries and spanning 12 sectors including disaster resilience and management. These highly customized smart hubs, have been created by using the SPACE factory, to support our work with the United Nations and to educate graduate students at Harrisburg University of Science and Technology. To pay special attention to Pandemics and other Disasters, we have created a small lab within the SGV called the *Smart Cities and Communities (SCC) Lab.* The SCC Lab [29] satisfies the aforementioned key requirements and is operational at present. We are using the SPACE Factory and the SCC Lab in teaching graduate courses in planning, architectures, integration and management of smart cities, communities and enterprises.

SPACE at present generates individual smart hubs for health, education, public safety, public welfare and several commercial sectors that collaborate with each other. It also generates, training materials and policy considerations (see Exhibit1 for a quick overview of the SPACE Environment and a definition of Smart Collaborating Hubs -- SCHs). The next sections give an overview of the SPACE capabilities (Section III), a discussion of the results so far (Section IV), and future areas of research (Section V).

Exhibit1: Example of a Software Factory

The SPACE (Strategic Planning, Architecture, Controls and Education) environment [21, 26] behaves as a software factory [1, 2] that quickly produces *Smart Collaborating Hubs (SCHs)* as shown in Figure1. An SCH is a center of activity that contains highly specialized and smart artifacts such as an Administrative Portal, a Citizen App, Training Materials and relevant Policies on a particular topic. Most importantly, all SCHs have pre-fabricated capabilities for collaboration with each other. The main input of SPACE is a Patterns Repository that contains an extensive library of business and technology patterns that can be combined into complex "bundles" to represent smart community centers, towns, cities and commercial enterprises spanning multiple sectors [21-24]. SPACE ePlanner, as shown in Figure1, quickly customizes, extends and reduces the patterns based on the population size and geographic location in phases P0 and P1. Later phases (P2, P3, and P4) further refine and enrich these patterns to produce highly specialized SCHs

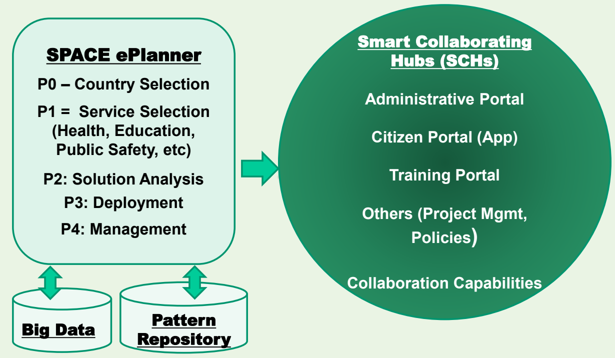

Figure1: SPACE Factory that Generates Smart Hubs

III. Overview of the SPACE Factory and Its Products

The SPACE (Strategic Planning, Architecture, Controls and Education) environment was initially developed as a computer aided planning tool for small to medium businesses. But now it has matured into a complete computer aided planning, engineering and management environment thanks to our Partnership with the United Nations SDGs (Sustainable Development Goals) initiative [23-27]. Specifically, we are currently leading a UN Partnership on ICT4SIDS (ICT for Small Islands and Developing States) that is utilizing the latest developments in ICT to accelerate all 17 SDGs in almost 140 countries [7, 24]. To meet this challenge, SPACE had to be architected as a 'factory' that quickly produces diverse smart collaborating hubs for different populations with varying human needs under applicable policies at a massive scale. Due to our experiences so far, we are proposing SPACE as a software factory that could address the aforementioned challenges as it become smarter gradually.

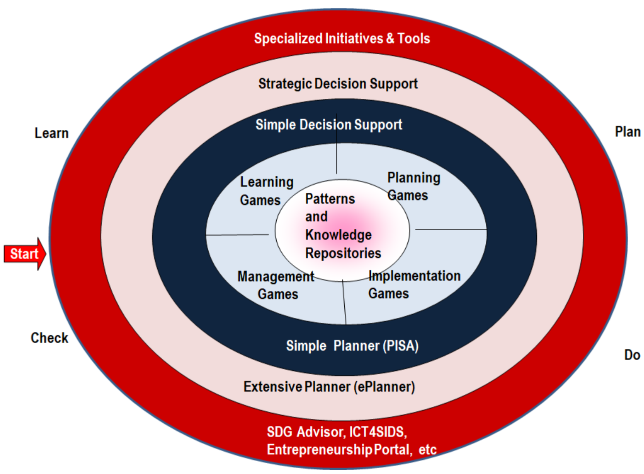

Figure 2: Conceptual Model of SPACE Capabilities

Figure 2 shows a conceptual model of SPACE as it exists at the time of this writing. SPACE uses an extensive array of capabilities that include patterns, gamifications, decision support and planning tools, and specialized tools that invoke different capabilities for different types of situations. SPACE consists of the following capabilities [22-26]:

- *Patterns and Knowledge Repositories* (the innermost circle) contain an extensive library of business and technology patterns and expose the users to educational materials, case studies, and examples needed throughout the cycle. These patterns and case studies span 12 sectors that include agriculture, education, health, public safety, public welfare and other vital sectors and are used throughout the aforementioned methodology. For example, healthcare patterns are used to create healthcare hubs.
- *Games and Simulations* (the next circle) that support decisions in strategic analysis, mobile services planning, interagency integrations and health exchanges, application migration versus integration tradeoffs, risks and failure management, and quality assurance. For example, disaster recovery (DR) gamifications are used to populate DR hubs.
- *Decision Support & Planning Tools* (the outer circles) contain strategic and detailed planning tools that systematically guide the users through various decisions in strategic planning, architectures, integration, acquisition, security, controls and project management activities. An example is the Extensive Planner (ePlanner) that is used to populate the smart collaborating hubs as illustrated in Figure1. ePlanner is the primary tool that supports the methodology (P0, P1, P2, P3, P4) shown in Figure1.
- *Specialized Tools* (the outermost circle) that present and customize special views of the inner capabilities for specific large scale projects. An example is the SDG Advisor that is used in phase P0 of the aforementioned methodology.

All SPACE capabilities are integrated with each other and collectively support numerous practical planning scenarios. For example, a health clinic for Haiti is first created by ePlanner by customizing the health clinic pattern for Haiti (the innermost circle) and then invoking other capabilities (the outer circles) that include gamifications, decision support tools, and relevant policies to build a smart collaborating clinic for Haiti.

IV. Initial Results – A Smart City & Communities Lab

We have used SPACE as a factory to generate the Smart City & Community (SCC) Lab that consists of a set of *Smart Collaborating Hubs (SCHs).* These hubs offer topic and location specific services shown in Table1 and also interconnected through a smart collaboration network with *some* Knowledge, Detection, Adjustment and Learning (KDAL) capabilities. A screenshot of the SCC Lab, displayed in Figure 3, shows a COVID Hub that provides some of the solutions mentioned in Table1 for COVID19, a DRM Hub that provides some of the solutions mentioned in a similar table for general DRM, a Digital Transformation Training Hub, a Digital Government Sample Hub, a Collaboration Matrix, and the SPACE Home Page.

SPACE initially resided on a private cloud but has now moved to a public cloud for high scalability and low latency. For the purpose of this paper, a *smart system* must have four features of smart humans -- *Knowledge (K)*: familiarity and awareness or understanding of someone or something; *Detection (D):* ability to discover, sense or feel an incident such as a problem or opportunity; *Adjust (A):* ability to change and act accordingly, e.g., stop and choose a different strategy; and *Learn (L):* the capability to *automatically* gain more knowledge (through machine learning) and to use it to do a better job in the future. KDAL capabilities can be achieved through a mixture of people, processes and technologies but technologies play a dominant role at present [11]. For better insights, case studies and examples, Exhibit2 suggests videoclips and other resources for hands-on experiments with SPACE and the SCC Lab.

We are using a system of systems approach to gradually make the SCC Lab smarter: a) gradually make the individual portals in each SCH smarter, b) make each SCH smarter by improving the collaboration between portals in each SCH, and c) make the overall SCC Lab smarter by making the collaboration *between* SCHs smarter through better user community involvement. Basically, smart cars gradually become more effective as better digitized road maps become available and smart cars and smart roads, with sensors, learn from each other and become smarter over time [27].

Figure 3: Sreenshot of the SCC Lab Home Page [29].

Exhibit2: Videoclips & Hands on Experiments

For Videoclips of specific Tools and Techniques:

- What is the SPACE Factory: 2 Minute Video Clip (http://ict4sids.com/ved9.html)
- What is a Smart Hub: 3 Minute Video Clip (http://ict4sids.com/ved14.html)
- How Does Collaboration Help a Smart Global Village: 4 Minute Video Clip (http://ict4sids.com/ved4.html)
- Computer Aided Planning Methodology: 5 Minute Video Clip (http://ict4sids.com/ved6.html). For more details (http://ict4sids.com/methodology.html)
- SDG Advisor: Video Clip (http://ict4sids.com/ved7.html), Link to the Tool (http://space4ict.com/pages/sdgsadv.aspx)
- UN ICT4SIDS Partnership site video tour -- please go to the site (www.ict4sids.com), and click on 'Video Gallery' (Red Button on Top of the screen). This will show you a list of many video clips

The SPACE site (www.space4ict.com) provides complete information about different layers of SPACE. Please login as a guest and conduct different experiments.

Smart Cities and Communities Lab (www.ict4sids.com/scc.htm) shows interesting examples of the smart hubs in operation at present. For hands-on experiments on SCC Lab, please login as a guest.

Smart Global Village (SGV) Sandbox (http://space4ict.com/njsamples/countryCount.aspx) shows over 700 portals in 130 Countries. Please login as a guest.

Additional Case Studies and Examples can be found in [23, 26, 31].

V. SPACE AS A FACTORY – RESEARCH AGENDA

Table2 gives a quick assessment of SPACE as a Factory in terms of the challenges posed in Section1, the current status of the factory at the time of this writing, and the future research directions. The future directions are further explicated in relevant notes.

Table2: Quick Assessment of SPACE as a Factory

Challenges Posed	**Current Capabilities**	**Research Directions**
C1: Solutions must be location specific (i.e., local considerations)	100%: All solutions are customized for location specific data from Big Data Sources	Expand Big Data by using ML to Use satellite images (See Note1)
C2: Solutions must be topic specific (i.e., hub on healthcare must have healthcare specific services)	70%: Most vital topics are covered in the Patterns Repository because these patterns contain 200 services that span 12 sectors	Expand the PARIS repository to cover more topics in utilities, finance, entertainment, etc). Expand PARIS to learn (See Note2)
C3: Compose larger solutions from smaller services to represent cities, etc	90%: Almost all smaller solutions generated by SPACE can be used to construct large and complex solutions	Larger solutions should carry more semantics and relationships (See Note3)
C4: Collaborations and integrations between solutions	80%: Extensive B2B collaborations between Smart Hubs are supported	Need to support trusted collaborations by using Blockchain (See Note4)
C5: Generated solutions must be smart (KDAL)	50%: Most generated solutions are rich in K but poor in DAL	Use Deep Learning extensively to improve DAL (See Note5)
C6: Factory itself must be smart (i.e., uses KDAL capabilities)	40% The SPACE ePlanner is rich in Knowledge (uses rules and patterns)	We need to beyond the ePlanner and move towards an Intelligent Factory (See Note6)
C7: Solutions must be generated rapidly (within one hour)	90% (most solutions are generated within 20 minutes but pre and post processing is manual)	Need to automate all pre and post processing activities (see Note7)

NOTE1: Location Specific Solutions. All solutions are customized for location specific data from Big Data Sources such as the World Bank, World Economic Forum, World Health Organization and several other open data sources. We are expanding Big Data capabilities by using ML/DL algorithms that extract valuable information from satellite images (e.g., the physical infrastructure weaknesses in poorer neighborhoods) to augment the readily available Big Data.

NOTE2: Topic Specific Solutions. Most vital topics are covered in the Pattern Repository. At the time of this writing, SPACE Pattern Repository has more than 200 services that span 12 sectors such as health, education, public safety, public welfare, agriculture, utilities, transportation, and ecommerce. We are always adding more business patterns to the PARIS repository so that we can model more enterprises. Our main area of research is *learning patterns*, i.e.. how can the Pattern Repository discover new patterns and keep updating the existing ones based on user operations.

NOTE3: Compose larger solutions from smaller services. Almost all services defined in the SPACE Pattern Repository can be used to construct large and complex solutions. Figure 4 shows four possible categories of simple to large and complex SCHs types in terms of services offered and the number of service providers. S1 represents single business service by a single provider, S2 represents a collection of services ("service bundle") by a single provider, S3 represents a business service shared by multiple providers, and S4 represents service bundles between multiple providers. This categorization can be used to model numerous SCC scenarios as shown in Figure 4. So far, we have been working with S1, S2 and S3 scenarios. We will focus more on the S4 scenarios, especially to enrich our Smart Global Village. The research question is -- how S4 scenarios can carry more complex semantics & relationships.

Providers (Orgs, Owners) \ Services	One	Many (Bundles)
Many	**H3: Large** **- One Service by Several Providers** **- Examples: Health Information Exchange, Entrepreneurship Network, Farmer's Network, eMarketPlace**	**H4: Extra Large** **-Many Services by Many Providers** **- Examples: Smart City, International Tourism Centers, Regional/State Centers, Smart Global Village**
One	**H1: Simple** **- One Service by One Provider** **- Examples: Mobile Health Clinic. Small Tourism Center, Weather Alert Service, 3D Printer Site**	**H2 : Medium** **- Many Services by One Provider** **- Examples: Community Center, Healthcare Center, eAgriculture Center, Smart Town**

Figure 4: Solution Categories from Simple to Extra Large

*NOTE4: Collaborations and integrations between solutions. E*xtensive B2B collaborations between SCHs are already supported at the time of this writing in the SCC Lab & SGV Sandbox. However, we need to better model and support trusted collaborations by using Blockchains (BCs) between SMBTs. Although B2B collaborations is overall an active area of work [8, 15], research on how B2B collaborations can save lives, manage and control the threats, and help transformation is relatively sparse. The core of our overall research approach is a collaboration model that distinguishes between large and small businesses (B versus b) and between large and small government agencies (G versus g) that participate in regional collaborations. We also introduce a network N of collaborators from the same agency (e.g., a health information exchange). This model is basically operational in the SCC Lab and an innovative B2B gamification is operational that combines B2B protocols, Machine Learning and Blockchains. In the future, we will pursue the following investigations: how can our collaboration model automatically select the right B2B protocols based on the size (e.g. g versus G) and type of SMBTs (e.g., a healthcare facility versus a bank), and how can the policies for small versus large players be adjusted automatically. We are exploring use of blockchains to support trusted B2B collaborations and enforce policies and smart contracts. A major challenge is that BCs are resource intensive which makes them useless for SMBTs. This could be possibly addressed by storing minimal information on the blockchain and then using concepts like zero knowledge proofs, also known as zk-SNARKS [16].

NOTE5: Generated Solutions must be smart (KDAL). Most solutions generated by the SPACE Factory (i.e., Smart Hubs and the Collaborating Network) are rich in Knowledge (K) but poor in Detection, Adjustment and Learning (DAL). We intend to use the latest developments in AI to improve DAL in the future. Our research approach is based on the following vision: SCHs at different locations specialize on different topics (e.g., healthcare, food and agriculture, entrepreneurship, and disaster resilience and management) *and* collaborate with each other to serve a community better. All the SCHs are interconnected through an ICT infrastructure for collaboration and each sector also has its own internal ICT infrastructure to support local collaborations. As stated previously, K capabilities of all SCHs and Collaborations are high but all others are minimal. *Our goal is* to especially make learning capabilities of the SCC Lab to be High by using *federated and socially guided machine learning* techniques among smart hubs that are used by different communities in the SCC [30, 6].

NOTE6: Factory itself must be smart (KDAL), The SPACE ePlanner is rich in K (it uses rules & patterns), but we need to go beyond the ePlanner and move towards an *Intelligent* Factory by exploiting the following ideas:

- All SPACE advisors should use AI at several levels. First, the advisors should learn about changes made in the patterns by the user interviews and adjust the patterns accordingly. They should also use supervised machine learning and Open Big Data from diverse sources to discover new patterns and situations.
- Natural language processing (NLP) should be used extensively to generate videoclips, summarize long case studies for educational purposes, offer multi-lingual support for diverse populations, and produce UML (Unified Modeling Language) diagrams based on functional descriptions.
- Blockchains should be used and explored for secure and trusted collaborations between different hubs.
- Deep learning and process mining should be investigated for automatic adjustment of the pattern repositories as more data becomes available from process mining.

NOTE7: Solutions must be generated rapidly. The Factory Process Model has the following activities:

- Preprocessing: location specific data & service selection
- Core Processing: solution generation (portals)
- Postprocessing: hub generation (including cyber physical artifacts by using 3D printing where possible)

The Core Processing at present is about 80% automated and takes less than 20 minutes to generate complete portals. But pre-processing and post-processing are somewhat manual and are the main bottlenecks at present. For example, ML &

satellites can be used to learn about the location of hospitals and police stations in case of disasters and then autonomous vehicles can be triggered as ambulances to rescue the wounded. The cloud, edge and fog computing can be used to fetch the most relevant data in this instance also.

VI. Concluding Remarks

This paper has outlined how a computer aided planning toolkit is evolving into a software factory for COVID and other disasters. We are very encouraged by the results so far and are planning to significantly accelerate our research as noted in Table2. We have learned that a software factory model is a natural fit for the SPACE environment and has a great deal of value for pandemics and other disasters. We have also learned that the SPACE Factory and the SCC Lab are very valuable tools in teaching graduate courses in planning, architectures, integration and management of smart cities, communities and enterprises. We are planning to make these tools widely available to other universities in the future.

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