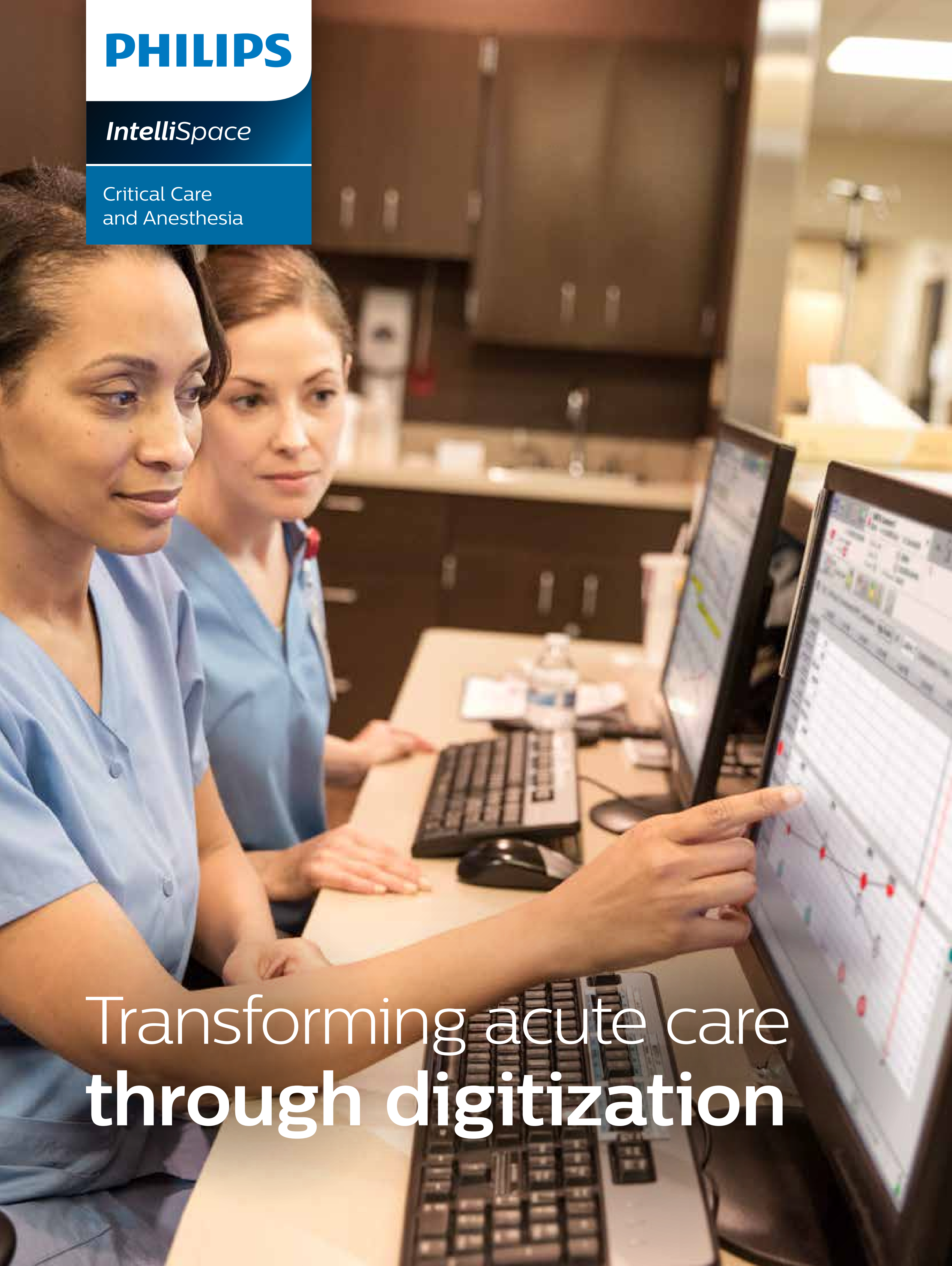

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*Intelli*Space

Critical Care
and Anesthesia

Transforming acute care **through digitization**

Executive summary

The trend to digitize acute care is rapidly growing worldwide, as healthcare systems struggle with increasing chronic conditions, reduced availability of expert clinicians, and financial constraints. We survey studies over the last two decades, showing how digitization has become essential for healthcare systems to improve efficiencies, connectivity and learning from their data for continuous improvement.

The effect on improved documentation is detailed-highlighting the improvement in data quality, reporting, utilizing analytics, and providing baselines. This leads to a reduction of errors, especially medication errors and adverse events. It is also combined with a reduction in time spent documenting, and an improvement of clinical workflows, especially covering patient admission and shift transition. The clinical outcomes affected are related to the reduction of errors, ventilation support, and the improved diagnosis and triage of patients. Furthermore, clinical decision support is now a major tool that utilizes digitized acute care systems. Based on existing guidelines and machine learning studies, it has shown clear benefits in allowing clinicians to detect deterioration earlier, highlight therapy options, and triage patient groups. This has led to a reduced length of stay, reducing unnecessary treatments, and interventions. Many of these clinical and operational outcomes can be translated to financial benefits with patients being given the right level of care at the right moment in time.* The next frontier will be the integration of smart clinical decision support systems using artificial intelligence (AI) to make healthcare more predictive and reduce the costs of several debilitating conditions.

Healthcare digitization worldwide: trends and challenges

Healthcare around the world is facing important challenges as both healthcare systems and governments are aiming to improve patient care while reducing costs and optimizing resources. There is a growing demand for improved access and affordability, as countries have to face increased disease prevalence, ageing populations, inefficiencies in care, hospital overcrowding, and constraints on healthcare workforce.[1] In terms of data management and information systems, several important trends are affecting healthcare systems:[2]

1. Moving from paper based to computer based systems
2. Moving from local to global information systems, connecting departments (radiology, intensive care, etc.) to hospitals and even systems across countries. Hospital consolidation, requiring common IT infrastructures, is also an important trend, especially in Europe and the US.
3. Outcome improvement based on data. This applies to clinical and financial outcomes combined with patient and family satisfaction.
4. The need for transparency, which is essential for improved quality and reduced costs, especially with healthcare becoming more regulated.
5. Increased focus on data security, privacy, and ownership.
6. Research based on data, leading to knowledge discovery, the creation of new protocols and guidelines, as well as the creation of baseline performance targets.
7. Augmenting numerical with more complex data types, combining imaging, clinical notes, patient history, and more recently novel genomic/proteomic data. This multi-faceted view of patient data has led to more patient-centered and personalized decision making.

In many markets, digitization has been instrumental in addressing these challenges, leading to a growing trend in healthcare IT. Digital technology has the potential to transform the way patients engage with services, improve the efficiency and coordination of care, and support people to manage their health and wellbeing.[3]

* The references to the above will be included throughout the document.

Adoption of digitized healthcare in different countries

Despite a rising trend, we are still far away from digitized healthcare achieving its full potential around the world.

USA

- The proportion of American hospitals with an electronic health record (EHR) has grown eight-fold from 9% in 2008 to 76% in 2014.[4]
- EHRs have also gained federal funding and support: The government has given $6.5 billion in incentives (2012) and launched the Health Information Technology for Economic and Clinical Health (HITECH) Act to motivate the implementation of EHRs.
- Increased funding for digital startups in the US healthcare market, exceeding $23 B in 2018.[5]
- The proliferation of healthcare IT systems did not directly translate to savings and improved results; with a large variation between hospitals across the US.

The United Kingdom[7]

- Adoption rates of EHRs are also high at around 90%. More than 50% of providers to invest in data sharing by 2020.
- However, beyond primary care, digital systems are diverse and fragmented. Acute trusts are less digitized, and they are less able to share information digitally.[3]

China[1]

- Fragmented healthcare systems where a major problem is the lack of interoperability.
- Dominated by local vendors.
- Uneven IT development, with tier I cities quite developed and poor infrastructure in rural areas. Leading cities, including Beijing and Fujian, are investing in regional healthcare information exchange systems.

France[6]

- High healthcare IT adoption with approximately 90% of healthcare providers having an EHR. Growth in hospital IT budgets since 2015 estimated at 20%.
- However, only 15% of hospitals share data beyond their network.
- Decreasing number of hospitals (-2.6%), and general care practitioners (-8%) between 2007 and 2017.

India[1]

- Public expenditure in healthcare is generally low leading to decreased IT adoption in the public sector.
- Generally, paper based systems.
- Legislative gaps in digital healthcare with a lack of standardization; despite recent government initiatives.

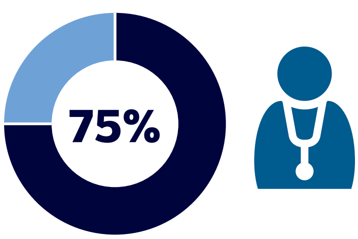
Australia[8]

- The government established the Australian Digital Health Agency in 2016 to create a national platform for digitized heath data- My Health Record, a 16-year $2B project that had technical glitches, and continues to have ongoing privacy and security issues. This has led more than 1 million people to opt out.
- Deficit in the number of health workforce (nurses and doctors)
- 50% of Australians have at least one chronic condition.

The map shown on the previous page highlights several of the trends in digitizing healthcare worldwide. The following is a summary of these trends which are prominent in certain geographies:

- Interoperability challenges between digital systems, especially in the Asia Pacific market, China as an example.
- The variation in digitization leading to a variation in care- evident many parts of the world. An example is in India's difference between rural and city hospitals.
- The adoption in EHRs on a country-level does not always translate to digitized acute care (UK).
- Concerns over security and privacy with people opting out of digitized national records, in Australia for example.
- The challenge to meet declining numbers of physicians and nurses (France and Australia).
- Spiraling costs (USA) do not always translate to improved outcomes. Financial constraints on healthcare are also evident in all markets, where providers are keen on seeing concrete outcomes for investments they make.
- Data overload has led to clinicians missing out on important trends and changes.[9] This has led to novel ways of data summarization and representation (several projects in the US).
- The interest in AI in healthcare has never been higher with new startups receiving funding (USA).
- The rise of chronic conditions and co-morbidities has put a strain on healthcare systems worldwide, especially Europe, the US, and Australia.
- New regulations are needed to deal with novel forms of healthcare data, as well as incentives for hospitals to adopt digitization as a strategy.

The case for acute care digitization



75% of physicians believe that digitalization of patient data could help them improve the quality of care.[15]

Acute care is a particularly important area where digitization is needed as a means of improving the quality of care and controlling spiraling costs. It is the most expensive, technologically advanced and human-resource intensive area of care. Yet, it is the area associated with the highest number of errors. In fact, nearly all ICU patients suffer a potentially life-threatening error during their stay with medication errors accounting for 78% of serious medical errors.[10,11] Decision-making and diagnosis are also more difficult in critical care due to the vulnerability of patients, who can have co-morbidities and deteriorate rapidly. A survey by Johns Hopkins University School of Medicine (USA), analyzing 540,000 deaths revealed that misdiagnosis is 50% more common in ICU patients than general hospital patients.[12] Keeping ICU patients longer than necessary, or unnecessarily admitting patients to the ICU, can be potentially harmful, as ICU stays have been linked to hospital acquired infections (HAI) occurring in approximately 10% of all ICU patients.[13] Globally, there is a general shortage of intensivists, who can suffer from burnout due to long hours and high time-pressure tasks. However, the demand of acute care is predicted to grow, with an increase in the elderly population, certain conditions (e.g. cardiac disease), and co-morbidities. To meet the higher demand for ICU beds, there is a need for improved triaging/allocation, ICU organization, and improved clinical outcomes leading to less readmissions.[14]

From the physicians' point of view, a recent survey of European Healthcare systems showed that more than 75% of physicians believe that digitalization of patient data could help them improve the quality of care in the next three to five years, as long as new systems ensure that information is secure.[15]

Improving information management and analytics

Improving information management and analytics

Critical care information systems are associated with several positive outcomes relating to information management.[16] Some of the highlighted outcomes in relevant studies are:

Improved data quality-completeness and correctness of data

This is a proxy for the completeness of care, which affects clinical outcomes.[17] Digital Healthcare systems can also provide smart CDSs (Clinical Decision Support) to indicate if a data field is out of range, which could prevent errors in charting as well as medication errors. A rather simple yet powerful application is using decision support based on rules assigning safe medication ranges for different patients, based on age, co-morbidities and conditions. A wrong medication is flagged immediately preventing errors that could be life threatening.

Improving feedback on performance criteria for individual staff members as well as teams[20]

Improving incidence reporting and documentation

This area was one of the key recommendations of the institute of medicine's (IOM) report: To Err is human. Electronic systems allow for targeted incidence reporting, effective triaging, and robust analysis of incidence reports. However, this needs to be combined with clinician engagement and sufficient action to lead to outcome improvements.[18]

Improved tracking of events

This is essential from a legal perspective, especially for archiving treatments of patients. Records need to be authenticated and certified, in a similar manner to written records. However, referring to previous cases is much quicker in a digitized system versus a paper-based system. The comparison of certain fields and tracing responsibilities to individuals is also easier.

Improving baselining and comparison to national databases

A good example is the UK's Intensive Care National Audit and Research Centre (ICNARC) Case Mix Program Database.[19]

Building new knowledge from gathered data

In the last decade, rich critical care databases have been essential in the development of new algorithms as well as discovering correlation between treatments, medications, co-morbidities, and outcomes. Some of the leading examples are the MIMIC dataset with around 40,000 critical care patients,[21] and the ERI database by Philips eICU Research institute containing more than 3 million ICU patient stays.[22]

Digitization leads to tangible clinical, financial and operational outcomes

Reducing errors in care

A 2017 report by the Organization for Economic Cooperation and Development (OECD) underscores the need for urgent change in patient safety worldwide, especially in reducing errors.[23] In high-income countries, one in 10 patients is adversely affected during treatment, and around 15% of hospital expenditure is due to mistakes in care or patients being infected while in the hospital.[15] These errors are even more prevalent in critical care. A study estimated that an average of 178 processes of care are delivered to each ICU patient per day with 1.7 of them associated with some error.[24] The same study identified 554 errors and over 200 serious errors in a single ICU over a 4-month period.

Reducing medication errors

Medication errors are the most common cause of medical errors and their consequences can be grave. These errors account for 78% of serious medical errors in the ICU.[10] Critically ill patients are prescribed twice as many medications as patients outside of the intensive care unit (ICU).[25] These errors can include errors in drug type, strength, frequency, interaction with other drugs, and failure to start or stop treatments. An integrative review by MacFie et al.[26] analyzed 40 studies revealing the pertinence of this problem in critical care settings, with incidences of medication errors varying from 5.1 to 967 per 1000 patient days, and adverse drug events (ADEs) from 1 to 96.5 per 1000 patient days. Critical care settings normally include vulnerable patients with a reduced physiological reserve, reduced ability to metabolize drugs, and alterations in pharmacodynamics. Polypharmacy (the use of multiple drugs to treat a condition) is common along with prescriptions of drugs to which patients have not been previously exposed. The use of high-risk substances and varied routes of administration is more prevalent and these factors occur in the setting of busy and highly pressurized environments. All these factors contribute to a high rate of medication errors. The most commonly implicated drug groups in these errors included cardiovascular, gastrointestinal, antimicrobial, hypoglycemic and analgesic agents.[26]

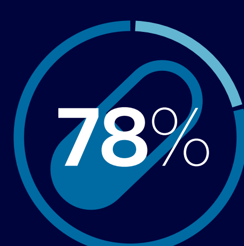
A review by Nuckols et al.[27] explored the effects of utilizing a computerized provider order entry system (CPOE) in preventing hospital medical errors and adverse drug events by analyzing 13 pre-post studies worldwide. Compared with paper-order entry, the use of CPOE was associated with half as many preventable ADEs (pooled risk ratio (RR) = 0.47, 95% CI 0.31 to 0.71) and medication errors (RR = 0.46, 95% CI 0.35 to 0.60)

In another review, the transition from paper-based ordering to commercial CPOE systems in ICUs was found to be associated with an 85% reduction in medication

Errors in the ICU

554 errors and over 200 serious errors in a single ICU over a 4-month period.[24]

In high-income countries, **one in ten patients is adversely affected during treatment.**[15]



Medication errors accounting for **78% of serious medical errors in the ICU.**[10]

15% of hospital expenditure is due to mistakes in care or patients being infected while in the hospital.[15]

prescribing error rates combined with a 12% reduction in ICU mortality rates.[28] Another systematic review by Charles et al.[29] analyzed several studies looking at different aspects of medication errors with similar conclusions. Table 1 includes some of the studies reviewed, as well as other studies who have shown promising results. In addition to the reduction of medical errors, these studies have shown positive effects on reducing the time from ordering to the administration of medications and decreasing duplicate orders. This is combined with increasing the accessibility of patient records allowing clinicians to work off-site if needed.

It is worth noting that these studies, although showing generally positive results, reveal some variability both in the baseline as well as the improvement achieved. Medical error reduction is a function of many factors including human factors, compliance, training and the integration of smart CDS (clinical decision support) in digital systems. These factors can vary between different hospitals leading to different results.

Reducing other types of errors

In addition to medication errors, there are several other error types in critical care, which also have serious consequences. They include active failures and latent conditions.[35] Active failures consist of missing an important action or step in a procedure, misdiagnosing, communication errors, and the violation of operating practices or standards. Latent conditions leading to errors include high workloads, insufficient training, supervision and auditing. The digitalization of critical care has helped address many of these errors:

- Finding information more efficiently, helping to reduce errors in misdiagnosis.
- Supporting teams to integrate best practices and operating procedures.[36] This is also combined with tracking compliance and rapidly identifying gaps.
- Improving the workload by reducing paperwork, which would increase time for patient care.
- Improved auditing allowing teams to understand treatment practices and ameliorate processes over time.[37]

Author / year	Study design	Outcome
Cartmill et al. (2012)[30]	Pre-post study of CPOE implementation	Average time from ordering to administration decreased from 100 to 64 minutes.
Magid et al (2012)[31]	Post-test study	Decrease in duplicate orders by 84.8%
Richardson et al. (2012)[32]	CPOE including bar-code scanning	Decrease in overall medication errors by 48%
Morriss et al. (2009)[33]	CPOE including bar-code scanning	Reducing the risk of targeted, preventable ADEs by 47%.
DeYoung et al. (2009)[34]	Bar-code assisted medication administration study (pre-post)	Reducing medication errors by 56%.

Table 1

Tele-ICU

30%

30% reduction in documentation time.[41]

50%

50% reduction in staff turnover rate over 3 years.[39]

250 lives

Saved more than 250 lives in one year through the use of tele-ICU.[45]

$62m

Saved $62M in healthcare costs in one year through the use of tele-ICU.[45]

Improving nursing workflow and efficiency

The growing elderly population, combined with enhanced life expectancy and improvements in the delivery of healthcare, have increased the demand for critical care services. However, the long-standing shortage of intensivist, nurses, clinical pharmacists, and respiratory therapists make it difficult to meet patient demands.[38] This is combined by a high burnout rate caused by tough schedules, long hours, difficult cases and increasing administrative duties. This raises the importance of workflow efficiency to allow the consistent delivery of high-level care. Digitizing critical care has played an important role, leading to several improvements in efficiency and workflow including:

- Positive impacts on communications between clinical teams, as perceived in surveys done with clinical teams before and after the implementation of a PDMS in the ICU.[39]
- Introducing checklists to improve data transfer and retention at care handoff points.[40]
- Reduced documentation time[36,39] by up to 30% in some studies,[41] reduced interruption rates, as well as time spent multitasking.[42]
- Increasing the time nurses spend with patients.[41,43]
- Reducing staff turnover rates. For example, in the Australian study by Fraenkel et al.,[39] an increase in nursing employment and a reduction of staff turnover rate by 50% was observed over 3 years after the integration of an electronic Philips PDMS (patient data management system) in a 12 bed ICU. This was accompanied with a significant reduction in rates of medication, intravenous therapy and ventilator incidents.
- Optimizing resource utilization,[41] especially by eliminating inefficient workflows and enabling analytics to create benchmarks and analyze performance (such as time spent documenting) against goals.

It is worth mentioning that in terms of time efficiency, critical care information systems require time to set up, integrate with existing infrastructure and train teams on different features. In addition, there is the customization time needed to adapt the systems to hospital workflows. Once they are up and running, the time spent in charting and updating patient records can be compared to paper based systems. Thus, the reduction in overall time has to be studied in context. In fact, some study results have shown variable results in terms of analyzing time alone as a feature.[44]

It has to be combined with clinical outcomes to make sure that the time saved has not had a negative effect on outcomes. Information systems are essential for these studies, as both time and outcomes can be tracked over time.

Enabling access to medical specialists

Digitized health information systems in the ICU have played an important role in enabling clinician access to patients, which is particularly evident in tele-health systems. Tele-health applied to critical care settings can reduce physician isolation, and improve the collaboration of providers.[45] Avera health for example, connected 36 hospitals across nine US states, reducing length of stay, mortality, cost of care, and clinician burnout.[45] They claim that in 1 year, they managed to save more than 250 patient lives and $62M in healthcare costs. Tele-ICU can leverage intensivist coverage providing expertise to a larger number of patients, and is particularly useful for hospitals in remote or rural areas, hospitals with few resources, and those with high mortality/LOS (length of stay) due to lack of expert care.

Development of clinical decision support (CDS) algorithms

The development of novel algorithms for clinical decision support in critical care has only been possible through digitization and improvements in clinical data management. The last decade has seen a boom in AI/analytics, where many established companies, universities, research groups, and startups have developed novel algorithms to address important challenges in critical care. The following list shows how analytics, based on large databases, can address some of these challenges:

- **Early detection of deterioration:**[46] This is especially important for conditions that have a huge impact on mortality and morbidity. Examples are sepsis,[47] acute kidney injury[48–51] and acute respiratory distress syndrome.[52] By alerting clinicians to higher risk patients, treatments can be administered early (or harmful medications can be stopped), leading to improved outcomes. These treatments can utilize standard protocols that are recommended for these conditions.
- **Improved triaging:** By using analytics, hospitals can improve admission, discharge, and triaging of patients to the right level of care.[53,54]
- **Improving clinical decision-making and medication dosing:** Examples include therapy decision support,[55] making sure the right medication is provided at the right time, and selecting treatment pathways for patients.[56]
- **Predicting outcomes of care:** This involves analyzing how certain treatments and therapies affect outcomes during hospital stay and after discharge,[57] as well as developing risk models for different patients.[58]
- **Discovering short-term and long-term trends in hospital data:**[59] These trends can highlight improvements in practice or shortfalls that need to be addressed.
- **Benchmarking practice and discovering areas of improvement.**[60]

In addition to digitization enabling the development of these algorithms and tools, it is a requirement for deploying them and achieving improved outcomes, especially in new clinics. Many of these algorithms require a set of input parameters that are available in information systems- usually in a standard data format. This standardization is key in enabling the integration and scaling of these algorithms across different sites. The monitoring of the effect of decision support on performance indicators is also enabled by careful digitization. This allows hospitals to track changes over time and identify gaps where improvements are needed.

Despite a boom in clinical decision support algorithms, the integration in clinics has not been as smooth as developing them on retrospective datasets. Successful deployment involves integration in clinical workflows and IT infrastructure, efficient training, as well as improving care processes.

Improving clinical outcomes

Digitization of healthcare in critical care has been associated with several improved clinical outcomes. Improved documentation, tracking, access to information, as well as adherence to guidelines and protocols have all contributed to enhanced outcomes. Table 2 below shows a list of outcomes based on evidence from different studies.

Outcome improved	Studies	Improvement
Reduced Length of Stay (LoS) in the ICU	Levesque et al.[61]	LOS (reduction by 20%) 8.4 ± 15.2 vs. 6.8 ± 12.9 days; $p = 0.048$
Reducing medication errors	Ali et al.[62] (other studies are given in the previous section)	Improving patient identification, allergy status completion, drug names and traceability
Improving nutritional support for ICU patients	Berger et al.[36] Strack van Schijndel et al.[63]	Higher energy delivery for ICU patients
Improving ventilator use	McCambridge et al.[64]	Significantly less use of mechanical ventilation due to the use of a health information technology bundle along with remote intensivist coverage
Reducing rates of mortality	McCambridge et al.[64]	Reduction of mortality rates by 29.5% (same study as above)

Table 2

Improving financial outcomes

The improvement of patient care, through enhanced documentation, reduced errors, improved detection of deterioration, and improved therapy can lead to significant savings combined with enhanced margins. Levesque et al.[65] analyzed the reduction of losses due to digitization in a tertiary hospital ICU. A reduction of coding errors was observed (7.9% vs. 2.2%, $p<0.001$). This decrease in coding errors resulted in a reduced difference between the potential and real ICU financial supplements obtained in the respective years (€194,139 loss in 2007 vs. a €1628 loss in 2008).

The estimated savings in the U.S. for eliminating redundant tests in hospitals was estimated in 2009 as $8B (2.7% of total inpatient costs). Redundant tests in critical care are a part of the problem, and the efficient use of documentation could help in reducing them.

Moreover, digitization plays an important role in enabling ICU telemedicine, which in turn has proven to be an important tool in cost reduction and management especially across different sites. A meta-analysis study showed Tele-ICU leading to reduced ICU length of stay and mortality.[66] A recent study investigating financial improvements due to the use of ICU telemedicine showed large improvements in annual case volumes (+38%) and direct contribution margins (increased by more than 6 fold).[67]

In fact, many of the clinical and operational outcomes we have covered in the previous sections can be translated to financial outcomes. Reducing errors is essential in increasing patient safety and providing better quality of care, leading to improved throughput and a reduction of unnecessary treatments and interventions. The same applies to detecting deteriorations earlier due to decision support and the correct implementation of guidelines. Improving the use of treatments (such as ventilator support and nutrition) also improves financial outcomes by reducing long term morbidity and unnecessary stay in the ICU. The translation from outcome improvement to financial results can vary between different geographies using different reimbursement systems. However, the previous sections provide clear proof that digitization can lead to improvements in critical care. The next frontier will be the integration of clinical decision support making healthcare more predictive and reducing the costs of several debilitating conditions.

Challenges in critical care information systems

The previous sections covered the benefits that come with the adoption of healthcare IT in critical care. However, there are several challenges associated with the adoption and use of these systems. These challenges can lead to disrupting patient care, and lead to inefficiencies or even patient harm in extreme cases. Some of these challenges are:[68]

- Poor user interfaces and fragmented displays
- Issues with system access and configuration
- Issues with software updates and the need for downtime
- Issues with documentation during downtime
- Issues with data storage and retrieval
- Issues with integration in existing hospital systems as well as other IT systems (Radiology, Patient monitoring)
- Security and data safety issues
- Issues with ageing hospital systems and technical infrastructure that could prevent digitization is some areas
- Training and continuing education for teams
- Communication issues especially between inter-professional teams
- Problems in bringing well-established teams to use these systems and include them in their workflow.
- Lacking policies and procedures that can help teams adopt digitized systems.

How to address these challenges and bring **innovation to your hospital?**

Hospitals that have adopted novel Healthcare IT systems have seen improved efficiencies as well as enhanced clinical and operational outcomes. The key to reaching these targets and addressing the challenges lies in carefully addressing the following areas:

1. **Selecting the right information system:** Hospitals need to justify a return on investment analysis, in terms of finances needed, staff-time/ training required, and time to integrate with existing systems. Ease of use, clear data access, workflow integration, and the ability to adapt over time are all key factors in choosing an optimal IT system. A focus on security and data privacy features is also essential.

2. **Building a long-term IT strategy:** This is important in selecting an information system that can adapt to changes over time. If hospitals are expanding to new areas/patient groups, or adding remote accessibility, it is important that they start building towards information systems that can support these functionalities.

3. **Managing integration and successful go-live:** Although project management is key here, the human element is sometimes the make or break factor. Having buy-in from clinical teams on the floor, IT teams responsible for the integration, and senior management is key. A shared vision is important to align teams on milestones.

4. **Follow-up and adaptation:** After securing a successful go-live, the teams must have regular follow-ups and adapt their IT system to their needs. Identifying clear targets and performance indicators would really help teams assess how well they are doing. Many systems fail because they are hard to change once customized for a certain hospital.

5. **Training, testing and more training:** Time is of importance for very busy clinical teams. It is important that these Healthcare IT systems help enable improved care rather than simply adding a burden on documentation and trouble shooting.

6. **Using IT systems to their maximum abilities:** Novel Healthcare IT systems have improved tools for integrating protocols, providing clinical decision support, and improving monitoring. However, many of these features can be overlooked when the focus is simply that of documentation. Clinical teams should be encouraged to take the leap from simply charting and recording data to using intelligent solutions.

7. **Straight forward user-interfaces and easy to use screens:** With improvements in visualization, it has become clear that winning Healthcare IT systems are those that provide access to data when it is needed and in the most appropriate format. Advances in user interfaces/mobile technology has rendered this possible through touch screens, remote access technologies, and adaptive visuals.

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