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SANOAT KORXONALARIDA ROBOTLASHTIRILGAN TEXNOLOGIK TIZIMLARDAN FOYDALANISH SAMARADORLIGINI OSHIRISHNING TASHKILIY-TEXNOLOGIK ASOSLARI

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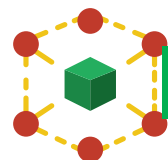
ANNOTATSIYA

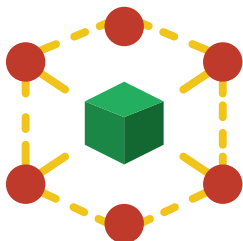
Maqolada sanoat korxonalarida robotlashtirilgan texnologik tizimlardan foydalanish samaradorligini oshirishning tashkiliy va texnologik asoslari tahlil qilinadi. Robotni alohida qurilma sifatida emas, balki texnologik mashina, sensor, PLC/SCADA, material oqimi va ishlab chiqarishni boshqarish tizimlari bilan integratsiyalangan kiberfizik ishlab chiqarish elementi sifatida baholash taklif etiladi. Xalqaro robototexnika federatsiyasi ma'lumotlariga ko'ra, 2024-yilda dunyoda 542 076 ta yangi sanoat roboti o'rnatilgan va amaldagi robotlar parki 4,66 mln donaga yetgan; yangi o'rnatishlarning 74 foizi Osiyo va Avstraliya, 16 foizi Yevropa va 9 foizi Amerika hissasiga to'g'ri kelgan. Global robot zichligi 10 ming ishlab chiqarish xodimiga 177 birlikka ko'tarilgan. Tadqiqotda OEE, takt va sikl vaqti, MTBF, MTTR, nuqsonlar darajasi, energiya sarfi, predictive maintenance va digital twin kabi mezonlar yagona samaradorlik tizimiga birlashtiriladi. Natijalar robotlashtirishning o'zi yuqori samaradorlikni kafolatlamasligini; maksimal iqtisodiy natija robot, texnologik jarayon, xizmat ko'rsatish va ishlab chiqarish logistikasini bir tizim sifatida optimallashtirish orqali olinishi mumkinligini ko'rsatadi.

Kalit so'zlar: sanoat roboti, robotlashtirilgan texnologik tizim, OEE, ishlab chiqarish samaradorligi, predictive maintenance, digital twin, PLC, MES, avtomatlashtirish, sanoat korxonasi.

АННОТАЦИЯ

В статье рассматриваются организационно-технологические основы повышения эффективности использования роботизированных технологических систем на промышленных предприятиях. Предлагается оценивать робот не как отдельное устройство, а как элемент киберфизической производственной системы, интегрированный с технологическим оборудованием, датчиками, PLC/SCADA, материальными потоками и системами управления производством. По данным Международной федерации





робототехники, в 2024 году в мире было установлено 542 076 новых промышленных роботов, а действующий парк достиг 4,66 млн единиц; 74% новых установок пришлось на Азию и Австралию, 16% — на Европу и 9% — на Америку. Глобальная плотность роботизации выросла до 177 роботов на 10 тыс. занятых в обрабатывающей промышленности. В исследовании OEE, такт и время цикла, MTBF, MTTR, уровень дефектов, энергопотребление, предиктивное обслуживание и цифровой двойник объединены в единую систему оценки. Показано, что сама по себе роботизация не гарантирует высокой эффективности: наибольший экономический эффект достигается при совместной оптимизации робота, технологического процесса, технического обслуживания и производственной логистики.

Ключевые слова: промышленный робот, роботизированная технологическая система, OEE, производственная эффективность, предиктивное обслуживание, цифровой двойник, PLC, MES, автоматизация, промышленное предприятие.

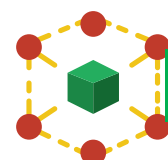
ABSTRACT

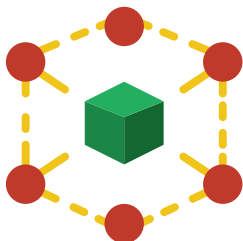
This article examines the organizational and technological foundations for improving the efficiency of robotized technological systems in industrial enterprises. Rather than treating the robot as an isolated machine, the study frames it as a component of a cyber-physical production system integrated with process equipment, sensors, PLC/SCADA, material flow, and manufacturing management systems. According to the International Federation of Robotics, 542,076 new industrial robots were installed worldwide in 2024 and the operational stock reached approximately 4.66 million units; Asia/Australia accounted for 74% of new installations, Europe 16%, and the Americas 9%. Global robot density rose to 177 units per 10,000 manufacturing employees. The study integrates OEE, takt and cycle time, MTBF, MTTR, defect rate, energy consumption, predictive maintenance, and digital-twin monitoring into a unified efficiency framework. The results show that robotization alone does not guarantee superior performance; the largest economic benefits arise when the robot, technological process, maintenance system, and production logistics are optimized as one integrated system.

Keywords: industrial robot, robotized technological system, OEE, manufacturing efficiency, predictive maintenance, digital twin, PLC, MES, automation, industrial enterprise.

KIRISH

Sanoat robotlari ishlab chiqarish tizimining unumdorligi, takrorlanuvchanligi va xavfsizligini oshirishda eng muhim avtomatlashtirish vositalaridan biriga aylandi. Avtomobilsozlik, elektronika, metallga ishlov berish, plastmassa, oziq-ovqat va logistika jarayonlarida robotlar payvandlash, yig'ish, yuklash-tushirish, paletlash, silliqdash, bo'yash va nazorat operatsiyalarini tobora keng qamrab olmoqda.





Robotlashtirishning iqtisodiy foydasi ko'pincha ishchi sonini qisqartirish yoki sikl vaqtini kamaytirish bilan izohlanadi. Amalda esa samaradorlik bundan ancha keng tushuncha. Robot yuqori tezlikda ishlashi mumkin, biroq unga material yetkazib berish kechiksa, stanok tez-tez to'xtasa, dastur almashinuvi uzoq davom etsa yoki sifat nazorati liniya oxirida nuqson topib qolsa, robotning nazariy unumdorligi korxona natijasiga aylanmaydi.

Shuning uchun robotlashtirilgan texnologik mashina yoki liniya tizimli obyekt sifatida baholanishi kerak. Robotning harakat trayektoriyasi, gripper va end-effector, texnologik stanok, datchiklar, boshqaruvchi kontroller, xavfsizlik zonasi, operator, material oqimi va texnik xizmat bitta ishlab chiqarish tizimining o'zaro bog'langan qismlaridir.

IFRning 2025-yilgi World Robotics ma'lumotlari 2024-yilda 542 mingdan ortiq sanoat roboti o'rnatilganini ko'rsatadi. Bu o'n yil avvalgi ko'rsatkichdan ikki barobardan ko'p. Robotlarning operatsion parki esa 4,66 mln birlikdan oshgan. Demak, masala endi robotlarni joriy etishdan ko'ra ularning real ishlab chiqarish samaradorligini qanday oshirishga ko'proq siljimoqda.

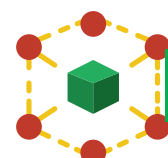
Samaradorlikni boshqarishda Overall Equipment Effectiveness (OEE) indikatoridan foydalanish muhim. OEE mavjudlik, ishlash tezligi va sifat ko'rsatkichlarini bitta integrallashgan mezonga birlashtiradi. Robotning downtime holatlari, mikroto'xtashlar, nominal tezlikdan past ishlash va nuqsonli mahsulot ishlab chiqarish bir vaqtning o'zida ko'rilmasa, uskunaning real samarasi noto'g'ri baholanishi mumkin.

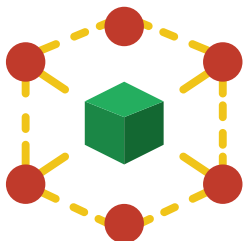
Industry 4.0 vositalari robot tizimlarini optimallashtirishga yangi imkoniyat berdi. Condition monitoring, predictive maintenance, digital twin va MES bilan integratsiya robot holatini real vaqt rejimida kuzatish, nosozlikni oldindan aniqlash, rejalashtirish va energiya sarfini muvofiqlashtirish imkonini beradi.

Ushbu maqolaning maqsadi sanoat korxonalarida robotlashtirilgan texnologik tizimlarning samaradorligini oshirishga ta'sir etuvchi texnik va tashkiliy omillarni tizimlashtirish, baholash mezonlarini ishlab chiqish va robotlashtirishni ishlab chiqarish boshqaruvi bilan integratsiyalovchi amaliy modelni taklif etishdan iborat.

METODOLOGIYA VA ADABIYOTLAR TAHLILI

Tadqiqot qiyosiy-analitik va tizimli yondashuv asosida olib borildi. Xalqaro robotlashtirish tendensiyalarini baholash uchun International Federation of Roboticsning World Robotics 2025 ma'lumotlari ishlatildi. Ishlab chiqarish samaradorligi OEE, Lean Manufacturing, Total Productive Maintenance, predictive maintenance va digital twin bo'yicha ilmiy adabiyotlar bilan birgalikda tahlil qilindi.





Robotlashtirilgan tizimning samaradorligi besh blokda ko'rib chiqildi: texnik mavjudlik, ishlab chiqarish tezligi, mahsulot sifati, texnik xizmat ko'rsatish va resurs sarfi. Bu yondashuv robotning faqat cycle time ko'rsatkichini emas, butun liniya natijasiga ta'sirini baholash imkonini beradi.

$OEE = Availability \times Performance \times Quality$ formulasi asosiy integrallashgan mezon sifatida olindi. Availability rejalashtirilgan ishlab chiqarish vaqtiga nisbatan uskunaning ishlash vaqtini, Performance amaldagi tezlikning ideal tezlikka nisbatini, Quality esa sifatli mahsulotning umumiy ishlab chiqarishga nisbatini ifodalaydi.

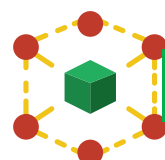
Texnik xizmat samaradorligi MTBF va MTTR orqali baholandi. MTBF nosozliklar orasidagi o'rtacha ishlash vaqtini, MTTR esa tiklashga ketadigan o'rtacha vaqtni ifodalaydi. Robot tizimida yuqori MTBF va past MTTR ishlab chiqarish uzluksizligi uchun asosiy shart hisoblanadi.

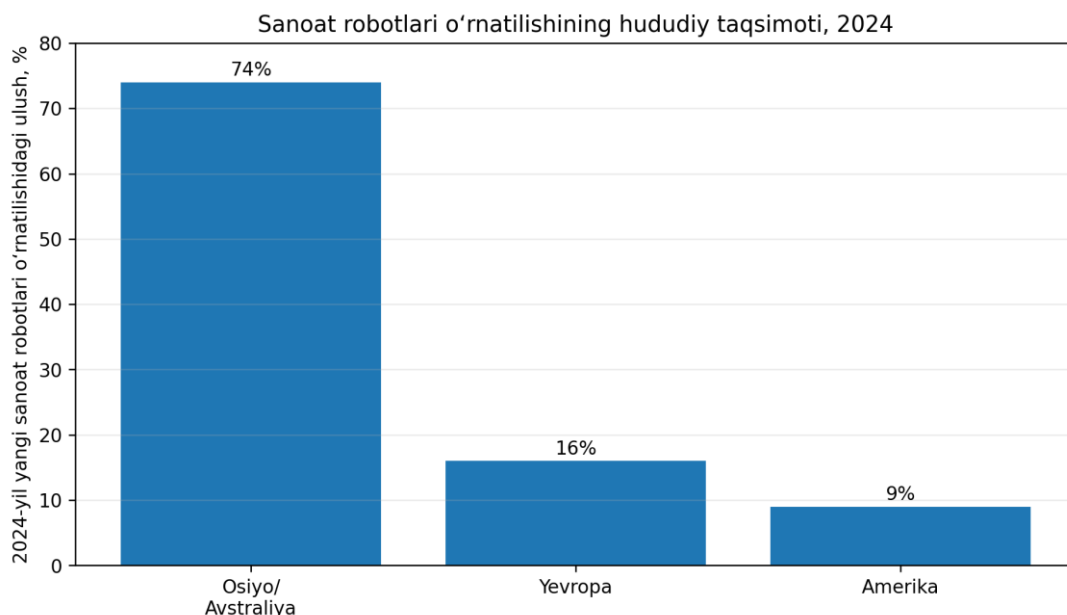
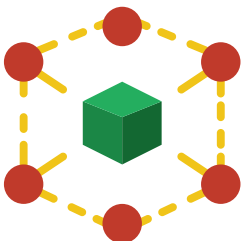
Raqamli monitoring blokida vibratsiya, tok, temperatura, servo yuklanishi, cycle deviation va alarm tarixining predictive maintenance uchun axborot qiymati ko'rib chiqildi. Digital twin esa robotning kinematikasi, takt, to'qnashuv zonalari va ishlab chiqarish ssenariylarini virtual muhitda tekshirish vositasi sifatida baholandi.

Birlamchi korxona ma'lumotlari berilmaganligi sabab maqolada sun'iy ravishda yaratilgan OEE yoki iqtisodiy samara foizlari qo'llanilmadi. Diagramma IFRning rasmiy 2024-yil global robot o'rnatish statistikasi asosida qurildi; samaradorlik bo'yicha jadvallar esa metodik indikatorlar tizimini ifodalaydi.

NATIJALAR

Xalqaro statistik ma'lumotlar robotlashtirishning ishlab chiqarish tizimlaridagi strategik ahamiyati keskin oshganini ko'rsatadi. 2024-yilda dunyoda 542 076 ta yangi sanoat roboti o'rnatilgan. Operatsion robotlar parki 4 663 698 birlikni tashkil etib, bir yil ichida 9 foizga oshgan. Yangi o'rnatishlarning 74 foizi Osiyo va Avstraliya, 16 foizi Yevropa va 9 foizi Amerika mamlakatlariga to'g'ri kelgan.

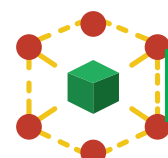


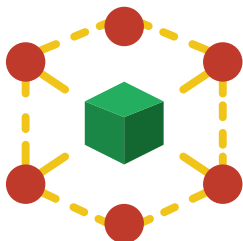


1-diagramma. 2024-yilda yangi sanoat robotlari o'rnatilishining hududiy taqsimoti. Manba: IFR, World Robotics 2025.

IFRning 2024-yil bo'yicha ko'rsatkichlarida global robot zichligi 10 ming ishlab chiqarish xodimiga 177 robotga yetgan. Yuqori robot zichligi bir tomondan kapital va avtomatlashtirish darajasini ko'rsatsa, ikkinchi tomondan korxonalarga robot parkini ekspluatatsiya qilish, texnik xizmatni standartlashtirish va foydalanish koeffitsientini oshirish vazifasini qo'yadi.

KPI	Hisoblash mantiqi	Robot tizimidagi ma'no	Asosiy yo'qotish	Ma'lumot manbai	Optimallashtirish yo'li
Availability	Run time / planned time	Robot va liniya ishga tayyorligi	Nosozlik, changeover, kutish	PLC/MES/alar m log	TPM, SMED, spare-parts
Performance	Actual rate / ideal rate	Nominal siklga qanchalik yaqin	Mikroto'xtash, sekinlashtirish	Cycle-time log	Trajectory va takt optimization
Quality	Good units / total units	Robot operatsiyasi barqarorligi	Payvand, pozitsiya, gripper xatosi	QMS/vision	Process control, sensor feedback





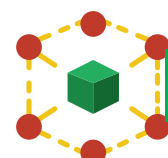
OEE	$A \times P \times Q$	Umumiy samaradorlik	Barcha yo'qotishlarning integrali	MES/OEE dashboard	Bottleneckga yo'naltirilgan improvement
MTBF	Run time / failures	Ishonchlilik	Takrorlanuvchi nosozlik	Maintenance CMMS	Condition/predictive maintenance
MTTR	Repair time / failures	Tiklash tezligi	Diagnostika va ehtiyot qism kechikishi	CMMS	Standard repair, spare-parts policy
Energy/unit	kWh / good unit	Energetik samaradorlik	Idle, noto'g'ri tezlik, ortiqcha harakat	Energy meter	Eco-mode, path optimization

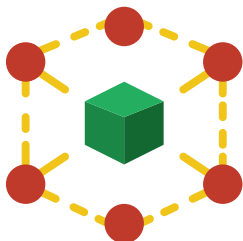
1-jadval. Robotlashtirilgan texnologik tizim uchun tavsiya etiladigan samaradorlik indikatorlari.

Samaradorlikni oshirishda eng katta metodik xato robot cycle timeini alohida optimallashtirib, liniya taktini e'tibordan chetda qoldirishdir. Agar robot detalni stanokdan tezroq qayta olsa-yu, keyingi operatsiya sekin bo'lsa, robot tezligining oshirilishi umumiy outputni ko'paytirmaydi. Aksincha, energiya, mexanik yuklanish va texnik xizmat ehtiyojini oshirishi mumkin.

Shuning uchun robot trayektoriyasini optimallashtirish bottleneck tahlili bilan birga olib borilishi kerak. Foydasiz burilishlarni kamaytirish, end-effector harakatini qisqartirish, zonalararo sinxronlash va parallel operatsiyalarni tashkil etish ishlab chiqarish siklini xavfsiz tarzda qisqartiradi.

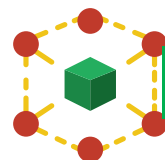
Yo'nalish	Muammo	Texnologik yechim	Kutiladigan operatsion ta'sir	Xavf	Nazorat indikator
Trayektoriya	Ortiqcha harakat va sikl	Offline programming/digital twin	Cycle time va energiya kamayadi	To'qnashuv/xavfsizlik	Cycle time, kWh/unit
Material oqimi	Robotning kutishi	Buffer, AGV/AMR, line balancing	Availability oshadi	WIP ortishi	Waiting time, WIP

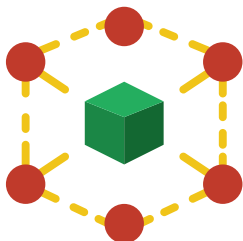




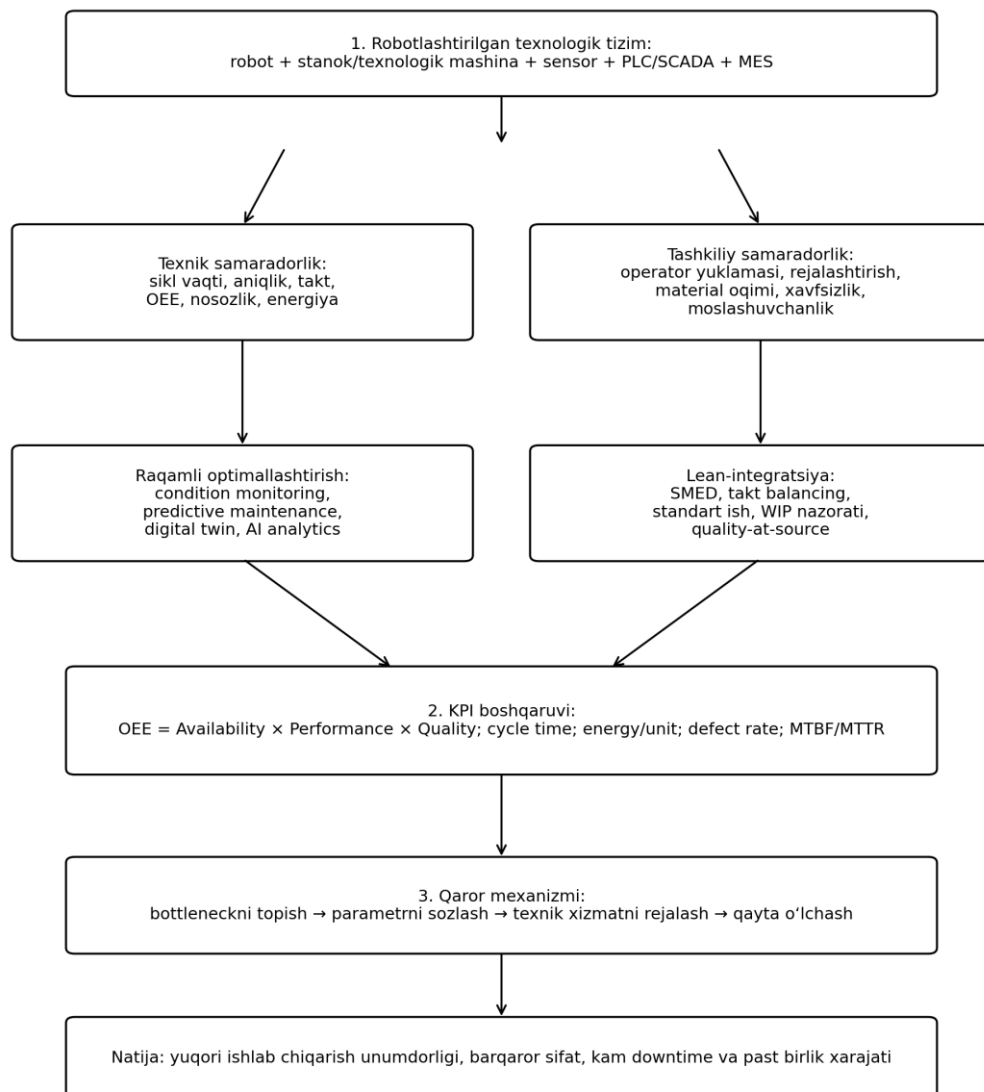
Texnik xizmat	Kutilmagan downtime	Condition monitoring + predictive maintenance	MTBF oshadi, MTTR kamayadi	False alarm	MTBF, MTTR
Quality	Takroriy nuqson	Vision, force/torque feedback	First-pass yield oshadi	Sensor drift	Defect rate, FPY
Changeover	Kichik seriyada uzoq sozlash	Quick-change gripper, recipe management	Moslashuvchanlik oshadi	Setup xatosi	Changeover time
Inson-robot hamkorligi	Ergonomik/xavfsizlik cheklovi	Cobots, safety scanner, risk assessment	Operator yuklamasi kamayadi	Safety risk	Near-miss, ergonomic score

2-jadval. Robotlashtirilgan ishlab chiqarishda samaradorlikni oshirishning amaliy yo'nalishlari.





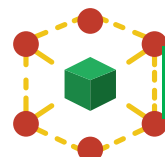
Robotlashtirilgan texnologik tizimlar samaradorligini oshirish modeli

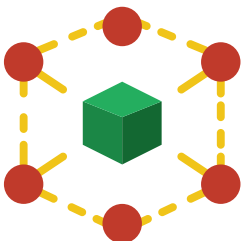


1-rasm. Robotlashtirilgan texnologik tizimlar samaradorligini oshirishning integratsiyalashgan modeli.

Predictive maintenance robot parkida reaktiv ta'mirdan holatga asoslangan boshqaruvga o'tish imkonini beradi. Servo motor tokidagi o'zgarish, reduktor vibratsiyasi, tormoz sikllari, temperatura va alarmlar ketma-ketligi nosozlikning erta belgilari bo'lishi mumkin. Bunday signallar CMMS yoki MES bilan bog'lansa, texnik xizmat ishlab chiqarishdan tashqari vaqtga rejalashtiriladi.

Digital twin esa robotni real liniyada to'xtatmasdan ssenariylarni tekshirishga yordam beradi. Yangi mahsulot turi, gripper, stanok joylashuvi yoki takt o'zgarganda virtual model orqali reachability,





collision, cycle time va buffer ehtiyojini oldindan baholash mumkin. Natijada commissioning va changeoverdagi noaniqlik kamayadi.

Boshqaru v bosqichi	Asosiy savol	Analitik vosita	Qaror	KPI	Amaliy natija
Diagnostika	Yo‘qotish qayerda?	OEE loss tree, Pareto	Bottleneckni tanlash	A/P/Q	Resursni to‘g‘ri yo‘naltirish
Model qilish	Nima o‘zgarsa natija yaxshilanadi?	Digital twin/simulation	Trajectory/buffer/layot	Cycle/takt	Xavfsiz virtual sinov
Joriy etish	Qanday o‘zgartirish kerak?	PLC/robot/ME S update	Parameter/sequence change	Output, energy	Real improvement
Monitorinig	Natija saqlanyaptimi?	Dashboard/SPC	Standardize or correct	OEE, FPY, MTBF	Barqarorlik
Doimiy yaxshilash	Keyingi cheklov nima?	PDCA/Kaizen	Yangi improvement cycle	Cost/unit	Uzluksiz optimallashtirish

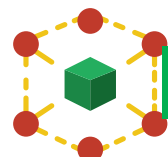
3-jadval. Robotlashtirilgan tizimni natijaga asoslangan boshqarish algoritmi.

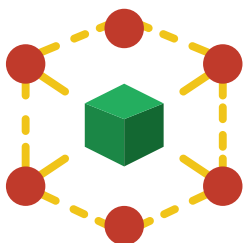
MUHOKAMA

Robotlashtirilgan tizimlarning samaradorligini oshirishda birinchi tamoyil — local optimization o‘rniga system optimizationdan foydalanishdir. Robotning o‘zini maksimal tezlikka chiqarish liniya throughputini oshirmasa, bunday sozlash foydasiz bo‘lishi mumkin. Korxona uchun asosiy mezon robotning harakat tezligi emas, sifatli mahsulotning vaqt birligidagi barqaror oqimidir.

OEE aynan shu sabab kuchli boshqaruv vositasidir. Availability, Performance va Quality alohida ko‘rilganda turli bo‘limlarning KPIlariga aylanib qolishi mumkin; ularni ko‘paytma shaklida baholash esa kichik yo‘qotishlar yig‘ilib katta samarasizlikka aylanishini ko‘rsatadi.

Robot parkida texnik xizmat strategiyasi ham iqtisodiy natijani keskin o‘zgartiradi. Reaktiv ta’mir dastlab arzon ko‘rinadi, lekin kutilmagan downtime liniya, operator, material va yetkazib berish majburiyatlariga birgalikda zarar yetkazadi. Predictive maintenance yuqori kritik robotlarda ayniqsa





samarali, biroq har bir sensor signalini murakkab AI tizimiga aylantirish shart emas. Oddiy trend, threshold va Pareto tahlili ham katta samara berishi mumkin.

IFR ma'lumotlariga ko'ra robotlar soni keskin oshib borayotgan sharoitda texnik xizmat ko'rsatish standartlari, zaxira qismlar va mutaxassislar tayyorlash robot xaridining o'zi kabi strategik masalaga aylanadi. Robot parki ko'payganda kichik downtime ham korxona miqyosida katta ishlab chiqarish yo'qotishiga aylanadi.

Digital twinning eng katta qiymati faqat chiroyli 3D modelda emas, ishlab chiqarish qarorini real liniyaga tegmasdan sinash imkoniyatidir. Robotlarning o'zaro zona almashinuvi, takt, buffer va material yetkazib berish virtual modelda tekshirilsa, commissioning davridagi sinov va xatolar kamayadi.

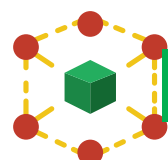
Robotlashtirish va Lean Manufacturing bir-biriga qarama-qarshi emas. Aksincha, avtomatlashtirishdan oldin ortiqcha harakat, kutish, WIP va noto'g'ri material oqimi bartaraf etilmasa, robot samarasiz jarayonni shunchaki tezroq takrorlaydi. Shuning uchun value-stream mapping, takt analysis va line balancing robot investitsiyasidan oldingi bosqichda qo'llanishi maqsadga muvofiq.

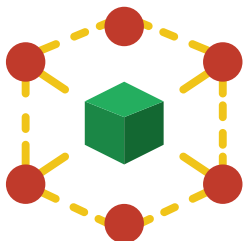
Kichik va o'rta korxonalarda robotlashtirishning asosiy muammosi ko'pincha yuqori boshlang'ich investitsiya emas, mahsulot nomenklaturasining tez o'zgarishidir. Quick-change gripper, vision guidance, recipe-based control va collaborative robots kichik seriyalar sharoitida moslashuvchanlikni oshiradi.

Robotlashtirilgan tizimda energiya samaradorligi ko'pincha e'tibordan chetda qoladi. Robotlar ishlab chiqarish bo'lmagan paytda idle holatda energiya sarflashi, noto'g'ri trayektoriya ortiqcha tezlanish va tormozlanishga olib kelishi mumkin. Energy/unit indikatori robot optimallashtirishni faqat sekundlar bilan emas, mahsulotga to'g'ri keladigan energiya bilan ham baholashga yordam beradi.

Inson-robot hamkorligi ishlab chiqarish samaradorligini oshirishning yana bir yo'nalishidir. To'liq avtomatlashtirish texnik yoki iqtisodiy jihatdan maqsadga muvofiq bo'lmagan operatsiyalarda robot takroriy yoki og'ir vazifani, operator esa qaror va moslashuvchan manipulyatsiyani bajarishi mumkin. Bunday tizimda xavfsizlik risk assessment va ergonomika KPilari ishlab chiqarish KPilari bilan birga yuritilishi kerak.

Robot tizimlarida ma'lumotlar integratsiyasi hal qiluvchi ahamiyatga ega. PLC alarm logi, robot controller, CMMS, vision tizimi va MES ma'lumoti alohida bazalarda qolsa, nosozlikning haqiqiy sababi ko'rinmaydi. Unified event history root-cause analysisni tezlashtiradi.





Samaradorlik loyihalarida iqtisodiy baholash ham faqat ishchi kuchini tejashga tayanmasligi kerak. Robot investitsiyasining qiymati yuqori throughput, scrapning kamayishi, sifat barqarorligi, yetkazib berishning ishonchliligi, xavfsizlik, energiya va maintenance xarajatlari orqali kompleks baholanishi lozim.

O'zbekiston sanoat korxonalari uchun bosqichma-bosqich yondashuv maqsadga muvofiq: avval OEE va downtime ma'lumotlarini ishonchli yig'ish, keyin eng katta yo'qotishli operatsiyalarda robotlashtirish yoki mavjud robotni optimallashtirish, so'ng predictive maintenance va digital twin kabi ilg'or vositalarni kritik uskunalarda joriy etish. Bu yondashuv texnologiyani maqsad emas, iqtisodiy natija vositasi sifatida ishlatishga yordam beradi.

XULOSA

Sanoat korxonalarida robotlashtirilgan texnologik tizimlardan foydalanish samaradorligi robotning texnik imkoniyatidan ko'ra uni butun ishlab chiqarish tizimiga qanchalik to'g'ri integratsiya qilishga bog'liq.

2024-yilda dunyo bo'yicha 542 mingdan ortiq sanoat roboti o'rnatilgani va operatsion park 4,66 mln birlikka yetgani robotlashtirishning ishlab chiqarish standartiga aylanayotganini ko'rsatadi. Endilikda korxonalar uchun asosiy raqobat ustunligi robot soni emas, ularning foydalanish darajasi va natijadorligi bo'ladi.

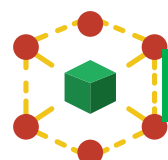
OEE, cycle time, takt, MTBF, MTTR, defect rate va energy/unit birgalikda qo'llanganda robotlashtirilgan tizimning real samarasi aniqroq ko'rinadi. Faqat bitta KPI bo'yicha optimallashtirish lokal natija berib, umumiy liniya samaradorligini oshirmasligi mumkin.

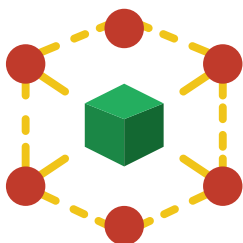
Predictive maintenance, digital twin va MES integratsiyasi kutilmagan downtime, commissioning va changeover yo'qotishlarini kamaytirish uchun samarali vositalardir. Biroq ularni Lean, TPM va standart ish tamoyillari bilan birlashtirish zarur.

Shunday qilib, samaradorlikni oshirishning eng to'g'ri modeli — robotni alohida avtomat emas, texnologik jarayon, material oqimi, texnik xizmat, sifat va raqamli boshqaruv bilan bog'langan integratsiyalashgan ishlab chiqarish tizimi sifatida boshqarishdir.

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